SARGENT, B.P., 2004 THICKNESS OF THE CHICOT AQUIFER SYSTEM SURFICIAL CONFINING UNIT AND LOCATION OF SHALLOW SANDS, SOUTHWESTERN LOUISIANA

STATE OF LOUISIANA

DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT OFFICE OF PUBLIC WORKS AND INTERMODAL PUBLIC WORKS AND WATER RESOURCES DIVISION



WATER RESOURCES

TECHNICAL REPORT NO. 73

THICKNESS OF THE CHICOT AQUIFER SYSTEM SURFICIAL CONFINING UNIT AND LOCATION OF SHALLOW SANDS, SOUTHWESTERN LOUISIANA



Prepared by the
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

In cooperation with the

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

STATE OF LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT OFFICE OF PUBLIC WORKS AND INTERMODAL PUBLIC WORKS AND WATER RESOURCES DIVISION

In cooperation with the

U.S. DEPARTMENT OF THE INTERIOR U.S. GEOLOGICAL SURVEY

WATER RESOURCES
TECHNICAL REPORT NO. 73

THICKNESS OF THE CHICOT AQUIFER SYSTEM SURFICIAL CONFINING UNIT AND LOCATION OF SHALLOW SANDS, SOUTHWESTERN LOUISIANA

By B. Pierre Sargent

U.S. GEOLOGICAL SURVEY

Published by

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

Baton Rouge, Louisiana

STATE OF LOUISIANA KATHLEEN BABINEAUX BLANCO, Governor

KAM K. MOVASSAGHI, Secretary DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

Edmond J. Preau, Jr., Assistant Secretary
OFFICE OF PUBLIC WORKS AND INTERMODAL

Zahir "Bo" Bolourchi, Chief PUBLIC WORKS AND WATER RESOURCES DIVISION

Cooperative project with the

U.S. DEPARTMENT OF THE INTERIOR GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY Charles G. Groat, Director

For additional information contact:

Zahir "Bo" Bolourchi, P.E. Chief, Public Works and Water Resources Division Louisiana Department of Transportation and Development P.O. Box 94245 Baton Rouge, LA 70804-9245 E-mail: BoBolourchi@dotd.louisian

E-mail: BoBolourchi@dotd.louisiana.gov

Fax: (225) 274-4322 Telephone: (225) 274-4171

Home Page:

www.dotd.louisiana.gov/intermodal/division

Charles R. Demas
District Chief
U.S. Geological Survey
3535 S. Sherwood Forest Blvd., Suite 120
Baton Rouge, LA 70816-2255

E-mail: dc_la@usgs.gov Fax: (225) 298-5490 Telephone: (225) 298-5481

Home Page: http://la.water.usgs.gov

CONTENTS

Abstract	1
Introduction	2
Purpose and Scope	4
Description of Study Area	5
Previous Investigations	5
Quaternary Deposition	6
Acknowledgments	6
Methods of Investigation	7
Data Compilation	7
Data Analysis and Map Generation	8
Thickness of the Chicot Aquifer System Surficial Confining Unit	9
Location of Shallow Sands within the Surficial Confining Unit	9
Summary and Conclusions	22
Selected References	27
FIGURES	
Map showing location of the study area in southwestern Louisiana	3
Diagram showing partial listing of hydrogeologic units in southwestern Louisiana	
3. Map showing thickness of the Chicot aquifer system surficial confining unit, southwestern Louisiana.	
4. Graph showing generalized east-to-west hydrogeologic section in northern Acadia Parish, Louisiana.	
5-16. Maps showing location of bottom of well screens and well logs with percentage of shallow sand within	
the Chicot aquifer system surficial confining unit in southwestern Louisiana by parish for:	
5. Acadia	14
6. Allen	
7. Beauregard	
8. Calcasieu	
9. Cameron	
10. Evangeline.	
11. Iberia	20
12. Jefferson Davis	21
13. Lafayette	23
14. St. Landry	24
15. St. Mary	
16. Vermilion.	26
TABLES	
1. Descriptive statistics of the depth of wells screened in the Chicot aquifer system surficial confining	
unit and well logs in southwestern Louisiana	11
and and wen rogo in southwestern Louisiana	11

CONVERSION FACTORS AND DATUMS

Multiply	Ву	To obtain
: ! (:-)	25.4	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi ²)	2.590	square kilometer (km ²)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1927 (NGVD 27). Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

THICKNESS OF THE CHICOT AQUIFER SYSTEM SURFICIAL CONFINING UNIT AND LOCATION OF SHALLOW SANDS, SOUTHWESTERN LOUISIANA

By B. Pierre Sargent

ABSTRACT

The Chicot aquifer system underlies an area of approximately 9,000 square miles in southwestern Louisiana and is the principal source of fresh ground water in the region. The dense surficial clays that confine the upper sands of the Chicot aquifer system in southwestern Louisiana are known as the Chicot aquifer system surficial confining unit. Although the confining unit may be relatively uniform in composition across large areas, interbedded sands that vary in areal extent and thickness are present within the confining unit. These interbedded sands are collectively known as the shallow sands of the Chicot aquifer system. The shallow sands occur irregularly throughout the confining unit and may be hydraulically connected to underlying aquifers. The shallow sands provide sufficient water for small-diameter wells that supply water for domestic, irrigation, or petroleum rig-supply purposes.

Drillers' logs and geophysical logs were used to define the thickness of the confining unit. The thickness of the surficial confining unit generally increases from north to south. In southern Vernon and Rapides Parishes, where the Chicot aquifer system crops out, the confining unit typically is less than 40 feet thick. The thickness of the confining unit generally increases southward, and generally ranges in thickness from 160 to 400 feet in coastal parishes with a maximum thickness of about 520 feet in Vermilion and St. Mary Parishes.

The locations of wells screened within the surficial confining unit and drillers' or geophysical logs showing shallow sands greater than 10 feet thick are mapped for 12 of the 15 parishes in the study area. The percentage of shallow-sand thickness in the confining unit is indicated for each log. Well-screen depths of 1,579 shallow wells used for domestic, irrigation, or petroleum rig-supply purposes were assumed to indicate the presence of productive shallow sands within the confining unit; however, only about 19 percent of the 2,098 logs analyzed indicate that shallow sands are present. The logs also indicate that the percentage of shallow-sand thickness in the confining unit can vary greatly across very short distances.

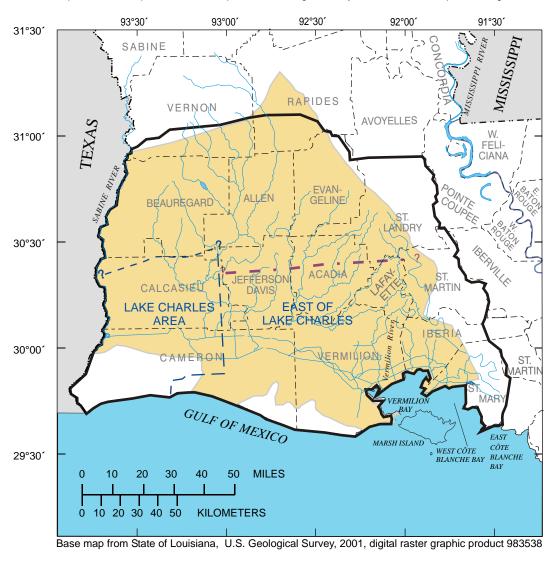
INTRODUCTION

Southwestern Louisiana is situated within the Gulf Coastal Plain Physiographic Province. The area is underlain by thick multilayered sequences of unconsolidated sedimentary deposits that alternate among gravel, sand, silt, and clay and that have a predominant dip to the south (U.S. Geological Survey, 1985, p. 229). Areally extensive zones of gravel and sand deposits, which form productive aquifer units, and the adjoining silt and clay deposits, which form confining units, are designated as the Chicot aquifer system (Nyman, 1984, p. 4). The Chicot aquifer system underlies an area of approximately 9,000 mi² in southwestern Louisiana (fig. 1) and is the principal source of fresh ground-water in the region (Lovelace, 1999, p. 2). In 2000, almost half of all ground-water withdrawals in Louisiana were from the Chicot aquifer system, and of this amount, more than half of the withdrawals were for rice irrigation (Sargent, 2002, p. 1). Dense surficial clays that overlie and confine the upper sands of the Chicot aquifer system makes the region ideal for rice farming by preventing major water losses through downward seepage (Lovelace, 1999, p. 2). These clays, and thin units of coarser material within the clays are known as the Chicot aquifer system surficial confining unit and will hereinafter be referred to as the confining unit.

The confining unit is composed of both Holocene- and Pleistocene-age sediments and was once thought of as an impermeable barrier to movement of contaminants from the surface to the underlying aquifers (Stanley and Maher, 1944, p. 13; Meyer, 1953, p. 2) (fig. 2). The impermeable barrier assumption has been reconsidered in recent years because of various incidents of subsurface contamination (Trudeau, 1994, p. 2). Hanor (1993) showed that the effective vertical hydraulic conductivity of surficial clay at a hazardous waste disposal site in southeastern Louisiana was as much as four orders of magnitude higher than reported laboratory measurements of clay core samples taken from the site. Hanor attributed the difference to the presence of minor sand beds and to secondary porosity and fracturing that occurred during deposition and sub-aerial weathering of the clay beds. Assuming that confining unit clays in southwestern Louisiana are similar to confining unit clays in southeastern Louisiana, the results of Hanor's research has implications for clays in the study area. Nyman and others (1990) simulated flow in the Chicot aquifer system and determined that, under 1981 conditions, vertical recharge from the land surface was now occurring throughout most of southwestern Louisiana.

Although the thickness of the confining unit may be relatively uniform across large areas, interbedded sands of varied areal extent and thickness are present within the confining unit. These sands are collectively known as the shallow sands of the Chicot aquifer system. The shallow sands occur irregularly throughout the confining unit and may be hydraulically connected to underlying aquifers. According to State well-registration records, more than 3,000 shallow, small-diameter wells that supply water for domestic, irrigation, or petroleum rig-supply purposes are screened in the shallow sands (Zahir "Bo" Bolourchi, Louisiana Department of Transportation and Development, written commun., 2002).

Little information is available on the thickness of the clay confining unit and the presence of sands within the confining unit; this information could be valuable for making land-use decisions and protecting shallow sources of ground water, as well as the deeper aquifers, from downward-moving contaminants. In 1996, the U.S. Geological Survey (USGS), in cooperation with the Louisiana Department of Transportation and Development (DOTD), began a study to document the thickness and extent of the confining unit and locations of shallow sands within the confining unit.





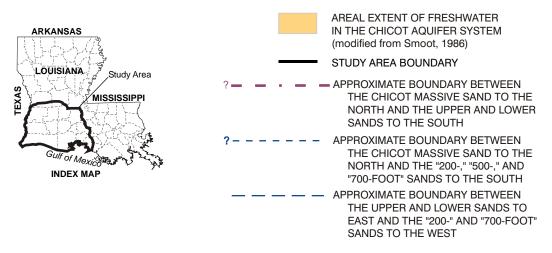


Figure 1. Location of the study area in southwestern Louisiana.

System	Series	Hydrogeologic Unit					
		Southwestern Louisiana					
		Aguifan	Aquifer or confining unit				
		Aquifer system	Lake Charles Area	East of Lake Charles			
	Holocene (Recent)	Chicot aquifer system	Shallow sand or surficial confining unit	Atchafalaya aquifer, shallow sand, or surficial confining uni			
Quaternary	Pleistocene		"200-foot" sand	Upper sand			
			"500-foot" sand	I			
			"700-foot" sand	Lower sand			
Tertiary	Pliocene Miocene	Evangeline aquifer					

Louisiana Department of Transportation and Development-U.S. Geological Survey Water Resources Cooperative Program

Figure 2. Partial listing of hydrogeologic units in southwestern Louisiana (modified from Lovelace and Lovelace, 1995).

Purpose and Scope

This report documents the thickness of the Chicot aquifer system surficial confining unit and the location of shallow sands within the confining unit. A map is presented that shows the areal pattern of confining unit thickness for all of Acadia, Allen, Beauregard, Calcasieu, Cameron, Jefferson Davis, Lafayette, and Vermilion Parishes and parts of Evangline, Iberia, Rapides, St. Landry, St. Martin, St. Mary, and Vernon Parishes, which are located along the confining unit boundaries. Mapping of small local variations at the base of the confining unit, such as incised-stream channels was beyond the scope of this report.

The location of 2,098 drillers' or geophysical logs, and the percentage of shallow sands within the confining unit (determined from the logs) are shown on maps. The location and depth to the base of well screens of 1,579 domestic, irrigation, or petroleum rig-supply wells that are screened in the shallow sands also are shown. Wells for which log data are available and wells screened in shallow sands often are clustered along roads and in populated areas. Other areas which consist of marsh land or extensive agricultural land far from roads, may have limited amounts of available subsurface information. The quantity and quality of data were insufficient to map the areal extent of individual shallow sand units.

This report provides a basis for collection of more detailed information about the transmissivity of the confining unit and the nature of the interconnection and relation between the confining unit and the deeper hydrogeologic units of the aquifer. Knowledge about the confining unit gained as a result of this study may contribute to the understanding of hydrogeologic conditions of surficial confining units in similar coastal settings.

Description of Study Area

The study area consists of the approximate extent of freshwater in the Chicot aquifer system in southwestern Louisiana (fig. 1). Along the Gulf of Mexico well log information was available that covered Cameron and Vermilion Parishes, so the study area was expanded beyond the areal extent of freshwater in the Chicot aquifer system. Marsh Island, an area in southern Iberia Parish that is mostly marshland bounded by West Côte Blanche Bay to the north and the Gulf of Mexico to the south, was not included in the study area, and no well log information was available. The study area is bounded by the Gulf of Mexico to the south, the Louisiana-Texas State line to the west, and alluvial sediments of the Atchafalaya River to the east. The Chicot aquifer system is cut into or overlain by alluvial sediments of the Atchafalaya River and the exact boundary between the sediments is indistinct. The eastern boundary of the study area, which was based on the presence of available well log information, includes most of Evangeline Parish and parts of Iberia, St. Landry, and St. Martin Parishes. The northern boundary of the study area is located in southern Vernon and Rapides Parishes, where the aquifer system and confining units pinch out near the surface. The existence of well logs also defined the northern boundary of the study area.

Previous Investigations

Previous studies have focused on the ground-water resources of southwestern Louisiana and the occurrence of freshwater in the Chicot aquifer system. Jones and others (1956) mapped the depth to the top of first major sands of the Chicot aquifer system using drillers' logs from water wells and electric logs from petroleum-test holes. The authors also presented detailed textural and lithologic descriptions of the confining unit based on formation samples collected from water-well test holes being drilled by municipalities and private interests during the course of the study.

Jones and others (1956) described two areas where the depth to a major sand is less than 50 ft thick. One area is in southern Vernon and Rapides Parishes, where the Chicot aquifer system crops out, and the other follows the course of the Vermilion River through Lafayette, St. Martin, and Vermilion Parishes. The greatest depth to a major sand described by Jones and others (1956) was more than 700 ft in Cameron Parish. Generally, a uniform depth of about 100 ft to a major sand was indicated throughout most of Evangeline, Jefferson Davis, and Acadia Parishes, western St. Landry Parish, and western Vermilion Parish (Jones and others, 1956, p. 139). Confining unit sediments were primarily attributed to Pleistocene-age back-swamp deposits of the Mississippi and Red Rivers (Jones and others, 1956, p. 82), but also may have included younger overburden sediments near the ground surface.

Harder (1960) mapped the top of the Chicot aquifer in Calcasieu Parish and noted that shallow wells in deposits of Holocene age supply small quantities of water. He stated that, "the exact thickness and areal extent of the sand phase of the Holocene deposits has not been determined; consequently, it is difficult to estimate the hydraulic characteristics and potential yield of these deposits." He also noted that locally there are shallow sands of Pleistocene age, which provide small quantities of water for domestic and stock purposes. Drillers' logs, electrical logs, and aquifer tests were the principal bases for determining the top of the Chicot aquifer.

Whitman and Kilburn (1963) examined ground-water conditions in southwestern Louisiana and discussed the Chicot aquifer along the Gulf of Mexico. Well log information from their report was used in the study described in this report. Harder and others (1967) examined the effects of ground-water withdrawals on water levels and saltwater encroachment in southwestern Louisiana and also provided well log information that was used in this study.

Nyman (1984) mapped the top of the major sands of the Chicot aquifer system, although the focus of the report was the occurrence of high-chloride water in the Chicot aquifer system. Geophysical and driller's logs were used to create the maps. Geohydrologic sections across different parts of the study area also are presented in the Nyman report.

Williams and Duex (1995) presented a map of the top of the upper sand of the Chicot aquifer system in Lafayette Parish and two geologic sections through the parish. Well Lf-488, documented previously by Jones and others (1954), was used as a representative correlation log; and information from the logs of approximately 40 petroleum-wells, 40 municipal water-wells, and several private wells were integrated with sand-analysis reports to produce detailed top-of-sand maps for shallow sand units in Lafayette Parish.

Quaternary Deposition

The geomorphic processes of lateral planation and vertical incision by meandering and braided streams, and eustatic changes in sea level over the last 2 million years produced the deposits that make up the Chicot aquifer system (Kniffen and Hilliard, 1988, p. 35). By reviewing the pattern of Quaternary-age deposition in the study area, a foundation is provided to conceptualize the surface of the base of the confining unit.

Over the last 2 million years, continental ice sheets advanced and retreated at least five times. The melting of the ice sheets, which were north of present day Louisiana, produced glacial streams, which carried an abundance of mineral material through Louisiana on their way to the sea. During each ice advance, the sea level declined and streams began to incise channels until the ice retreated and a corresponding rise in sea level occurred. As the shoreline moved inland the incised channels filled with sediment and the pre-existing surface sediments were reworked. The glacial streams deposited more sediment than they removed, so terraces of fine-grained material were formed over time (Kniffen and Hilliard, 1988, p. 41).

Saucier and Snead (1989) delineated three terrace-like Pleistocene-age sedimentary units near the surface: the Upland, Intermediate, and Prairie Complexes. At land surface, these units have an east-to-west orientation, paralleling the Gulf of Mexico coastline. The Upland Complex is the northernmost band in the study area and consists of fluvial deposits from both glacial and non-glacial sources as well as higher fluvial terraces. South of the Upland Complex, the Intermediate Complex is composed of fluvial deposits of the Mississippi River, its tributaries, and coastal plain streams, and includes terrace deposits. The Prairie Complex is nearest to the Gulf of Mexico and includes the results of a diverse depositional sequence of the Mississippi River, its tributaries, and coastal plain streams. Saucier (1994) listed the major depositional environments for the Prairie Complex as meander belt, Red River deltaic, nearshore marine, and undifferentiated coastal plain. The net result of Quaternary-age deposition in southwestern Louisiana is a great variation in sediment size and distribution throughout the area. As a result, the surface representing the base of the confining unit is assumed to be a composite of multiple discontinuities with depressions and ridges, rather than a flat, continuous sheet. Regionally, however, the slope of this surface generally is to the south, following the orientation of the underlying aquifer units and the overlying land surface.

Acknowledgments

The author wishes to thank Flozelle C. Roberts, formerly of the USGS, who assisted in compilation of the well log information, and C. Paul Frederick of the USGS who conducted an initial review of well logs. The Louisiana Department of Natural Resources provided important geophysical information in areas where data were scarce. The author gratefully acknowledges the cooperation of Zahir "Bo" Bolourchi,

Chief of Public Works and Water Resources Division, Louisiana Department of Transportation and Development, for assistance provided during the study and preparation of the report. In addition, Louisiana Department of Transportation and Development provided well-location and well-construction information.

METHODS OF INVESTIGATION

Two sets of data were used in this study. One set included data from geophysical or drillers' logs from selected water wells or test holes. Logs that completely penetrated the confining unit were used to map the thickness of the confining unit and provide information on shallow sands within the confining unit. Data from the 2,098 well logs compiled for this study are presented in a data report by Sargent and others (in press). Well log descriptions, the thickness of the confining unit, and depths to the top and bottom of shallow sands are presented by parish and well identifier in a tabular format. The data report also includes a detailed description of the method used to categorize and compile the log data for this report.

The second set of data included the depth to the base of the screened interval of 1,579 wells, hereinafter referred to as shallow wells, which were screened in the shallow sands and used for domestic, irrigation, or petroleum rig-supply purposes. These data were mapped to indicate the presence of shallow sands. Because shallow wells did not completely penetrate the confining unit or shallow sands within the confining unit, drillers' logs from these wells were not used in this report for mapping the thickness of the confining unit or depths to the top and bottom of shallow sands. Methods used for data compilation, data analysis, and map generation are described in the following sections.

Data Compilation

Drillers' logs and/or geophysical logs with corresponding location information for the well or test hole were compiled into a data set and used to define the depth to the base of the confining unit and identify shallow sands within the unit in southwestern Louisiana. The locations of wells and test holes were obtained as latitude and longitude values from well registration forms. Drillers' logs were available for over 10,000 water wells in the study area. However, the quality and completeness of these logs vary greatly. Drillers collecting lithologic data are mainly concerned with the location of major aquifer units that are capable of supplying long-term yields to wells. When drilling through a thick confining unit, drillers may fail to note lithologic information such as thin sand beds. Therefore, the quality and completeness of each drillers' log was evaluated before it was included in the data set. Drillers' logs that typically used non-geologic terms, such as gumbo or muck, and had lithologic intervals rounded to 100 ft intervals were unacceptable and not used. Drillers' logs that included lithologic descriptions, such as particle size--sand, silt, and clay, with relatively detailed resolution, that is, lithologic intervals rounded to 10 ft intervals or less, were included in the data set.

For water wells for which both a drillers' and geophysical log were available, the driller's and geophysical logs were compared to verify thickness values. In some instances, the geophysical log did not start at the ground surface, and information from both logs was combined to create a composite log. For each location, only one value was designated as the confining unit thickness for that point.

Information from two additional sources also was utilized so that the log data from water-well or test-hole registration forms would not be the sole determinant of confining unit thickness throughout the study area. Geophysical logs from petroleum wells were used in some areas where logs from water wells were sparse or unavailable. Because the first 200 ft below the land surface typically is not logged for petroleum wells, only a small number of these could be used to delineate the thickness of the confining unit. Both drillers' and geophysical log data from published reports also were used. Reports by Jones and others (1956), Harder (1960), Harder and others (1967), Nyman (1984), and Whitman and Kilburn (1963) provided 37, 29, 7, 63, and 4 data points, respectively.

Additional information on the location of shallow sands was obtained from well-screen depths and locational data of 1,579 shallow wells used for domestic, irrigation, or petroleum rig-supply purposes. Screen depths were assumed to indicate the presence of productive shallow sands within the confining unit. This information was obtained from the DOTD well-registration data base. In some instances, a drillers' log may not record the presence of a shallow sand, but a well screened within the confining unit may indicate a shallow sand near that location. The location and depth to bottom of screen of the shallow wells are displayed on maps that also display well logs with shallow sands within the confining unit for comparison purposes. Sand thickness at shallow wells was not assumed equivalent to their screened intervals and was not determined for these wells.

Data Analysis and Map Generation

Depths to the base of the confining unit and shallow sands within the confining unit were determined for each log. The base of the confining unit was identified as the top of first massive sand unit. Massive sand units often were distinguishable not only by thickness, but by coarse basal sediments, which typify sands of the Chicot aquifer system. The thickness of the confining unit was determined by measuring the approximate depth from the ground surface to the top of the massive sand unit. In areas where a massive sand is present within the confining unit, but is directly on top of a Chicot aquifer unit, the thickness was determined from ground surface to the top of the first massive sand. Some previous investigators designated the first sand unit, irregardless as to whether it is a massive sand, as within the confining unit and thus mapped a greater depth to the base of the confining unit.

For example, in Vermilion Parish, a shallow massive sand (formerly called the Abbeville unit) is present within the confining unit (Nyman, 1984, p. 21 and fig. 11). The shallow sand ranges in thickness from 100 to 250 ft and directly overlies what is typically considered the first major aquifer unit of the Chicot aquifer system in this area, the "upper sand" (Nyman, 1984, p. 21 and fig. 11). Because the clay layer separating this sand from the upper sand is thin or missing and this sand is in direct hydraulic communication with the upper sand, the top of this sand was used as the bottom of the clay-confining unit.

Well-log data were grouped by area and the confining unit thickness values were compared for consistency within the area. For instances in which a well log showed an extreme thickness that conflicted with other logs in the same area, the outlier log was deleted from the data set. Although outlier well-log data may be valid, the mapping of local variations in the base of the confining unit, such as those created by the filling of incised channels, was beyond the scope of this report.

The depths to the tops and bottoms of shallow sand units 10 ft or more in thickness were determined from well logs. A shallow sand thickness of at least 10 ft was used to identify possible productive sand units within the confining unit. For each log, the thickness of all shallow sands (10 ft or greater) were totaled and divided by the thickness of the confining unit on the log to determine the percent sand thickness within the confining unit.

All data were entered into a geographic information system (ArcInfo) to analyze the areal distribution of logs and generate maps of the confining unit thickness, the location of wells screened in shallow sands, and the percent sand thickness within the confining unit. To generate the map of confining unit thickness, a statistically-based interpolation method, kriging, was used. Kriging provides an exact interpolation at points where data are provided, is particularly applicable for making estimates where few data points exist, and provides error estimates (Dunlap and Spinazola, 1984, p. 5). The spatial pattern of wells in the study area is such that wells are clustered in some areas, but absent in others. Drilling of new wells was beyond the scope of this study; therefore, kriging was an appropriate interpolation tool for estimating the confining unit thickness in areas were data were sparse or absent.

The thickness of the confining unit was then contoured using a 40-ft contour interval in most areas. In some coastal areas where data were sparse and the confining unit thickness rapidly, an 80-ft contour interval was used. The accuracy of the confining unit thickness contours is a function of the quality and density of the data and the power of the interpolation technique (Burrough and McDonnell, 1998). The estimated error at any point on the thickness map is plus or minus 24 ft.

The locations of wells screened in shallow sands and logs showing the percent sand thickness within the confining unit of individual parishes also were mapped. For mapping purposes, the depth to the base of the well screen was used to indicate the depth of a sand. The base-of-screen depths were grouped in intervals of less than 50 ft, 50 to 100 ft, 100 to 200 ft, and greater than 200 ft. Wells screened in shallow sands often were clustered in population centers. Many of the clustered wells were screened at a similar depth, indicating the presence of a productive sand. In some areas, wells were screened at many different depths, indicating the presence of multiple shallow sands in the area.

The percentage thickness of shallow sands within the confining unit was computed from well logs with a sand interval greater than 10 ft. Where present, percentages were grouped in intervals of 1 to 20, 20 to 40, 40 to 60, 60 to 80, and 80 to 100 percent. Only about 19 percent of the logs indicated shallow sands were present, and the percent sand thickness varied greatly across very short distances. Wells with drillers' log data showing as much as 60 percent sand and shallow wells screened in shallow sands, were often surrounded by wells with drillers' logs that did not encounter sand. These variations may be indicative of the intermittent nature of the shallow sands, but may also illustrate differences in drillers' interpretations that were recorded on logs.

Because of poor areal distribution of well data, the varied quality of the log data, and the intermittent nature of the shallow sands, the areal extents of individual shallow sands could not be mapped. Similarly, the presence or absence of shallow sands could not be inferred for areas where well or log data are sparse or absent.

THICKNESS OF THE CHICOT AQUIFER SYSTEM SURFICIAL CONFINING UNIT

In the study area, the thickness of the Chicot aquifer system surficial confining unit ranges from less than 40 ft along the northern boundary to 520 ft in the southeastern part of the study area, along the Gulf of Mexico (fig. 3). In general, the confining unit thickens southward as its base dips toward the Gulf, conforming to the orientation and dip of the underlying aquifers (Walters, 1996, sheet 1). An exception to the southward thickening occurs in parts of Vermilion and Lafayette Parishes, along the approximate route of the Vermilion River (fig. 1), where the confining unit thins to between 40 and 80 ft thick (fig. 3). This may be evidence of an ancestral Mississippi River floodplain or delta (Kniffen and Hilliard, 1988, map 14). A few miles southeast of this area, the confining unit thickens rapidly to its greatest thickness around the southern part of Vermilion Bay and at points along the coast of East and West Côte Blanche Bays (fig. 3).

LOCATION OF SHALLOW SANDS WITHIN THE SURFICIAL CONFINING UNIT

The presence of shallow sands was documented in 12 of the 15 parishes in the study area. In the remaining three parishes, Vernon, Rapides, and St. Martin Parishes, well-log data indicated no sand intervals greater than 10 ft thick. Table 1 lists descriptive statistics by parish from rural-domestic water-supply wells screened in the shallow sands, including the total number of wells, range of depths to base of well screen, and mean depths to base of well screen. Table 1 also lists descriptive statistics by parish from

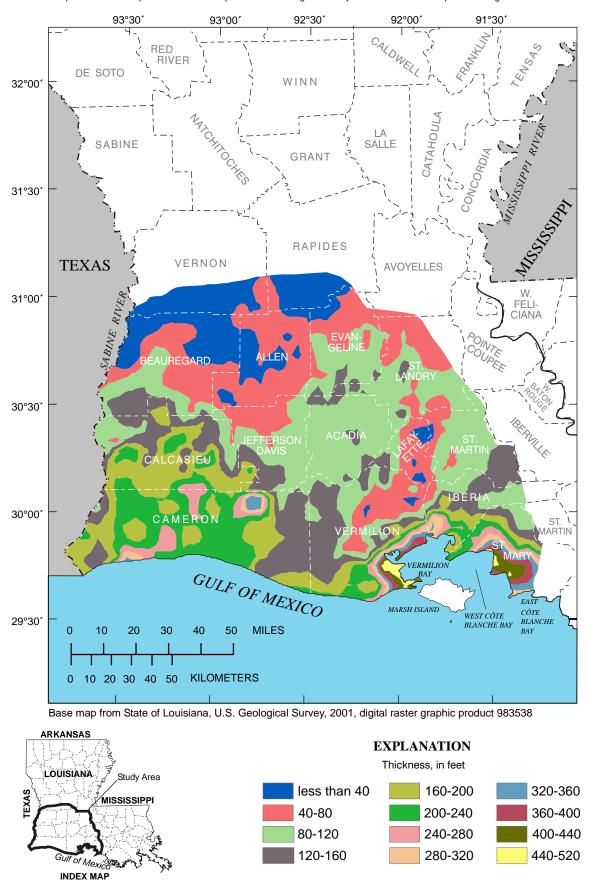


Figure 3. Thickness of the Chicot aquifer system surficial confining unit, southwestern Louisiana.

well logs including total number of well logs, percentage of logs with shallow sands (sand intervals 10 ft or greater), the range and mean depths to the base of shallow sand intervals, the range and mean of shallow sand interval thickness, and the range and mean of percent shallow sand thickness of the confining unit.

A generalized east-to-west hydrogeologic section of the Chicot aquifer system surficial confining unit in northern Acadia Parish shows the location of shallow sands and wells screened within the confining unit (fig. 4). If the section is typical of the confining unit, sand and screen data indicate sands generally are not areally extensive, and may occur at various depths. Also, sand units 10 ft or greater in thickness generally constitute a small part of the confining unit. The well logs indicating no sands may be due to the actual absence of sand or the variability of drillers' interpretations of the confining unit sediments. Figures 5 through 16 show locations of well logs and wells screened in shallow sands, and the percent sand thickness within the confining unit in each of the 12 parishes.

Table 1. Descriptive statistics of the depth of wells screened in the Chicot aquifer system surficial confining unit and well logs in southwestern Louisiana

	Wells screened in surficial confining unit			Well logs (drillers' and geophysical)							
		Depth to base of screen		Total	Logs with shallow	Depth to base of shallow sands		Thickness of shallow sands		Percentage of shallow sands ²	
Parish	Total number	Range (feet)	Mean (feet)	number of logs	sands ¹ (percent)	Range (feet)	Mean (feet)	Range (feet)	Mean (feet)	Range (feet)	Mean (feet)
Acadia	80	16-103	39	344	9	13-130	67	10-55	23	6-62	21
Allen	6	17-40	27	101	7	15-50	34	10-46	19	15-73	35
Beauregard	63	14-46	34	61	13	26-90	50	10-37	21	8-61	32
Calcasieu	786	4-250	63	242	42	18-247	96	10-110	35	4-71	18
Cameron	101	7-325	127	97	24	24-272	165	15-107	49	5-71	25
Evangeline	42	18-75	35	140	23	15-143	96	10-92	30	7-67	25
Iberia	59	13-270	86	93	19	35-344	116	10-60	19	3-23	12
Jefferson Davis	69	11-210	66	250	13	18-129	80	10-90	34	3-81	34
Lafayette	73	5-116	36	148	14	30-132	71	10-95	23	11-68	26
St. Landry	45	12-110	27	204	18	18-144	85	10-107	39	7-82	36
St. Mary	11	10-326	183	32	19	140-259	170	17-82	38	6-41	18
Vermilion	244	12-350	98	225	27	22-280	99	10-120	37	8-82	32

¹ Percentage of logs with sand intervals of 10 ft or greater.

² Percentage of confining unit composed of sand.

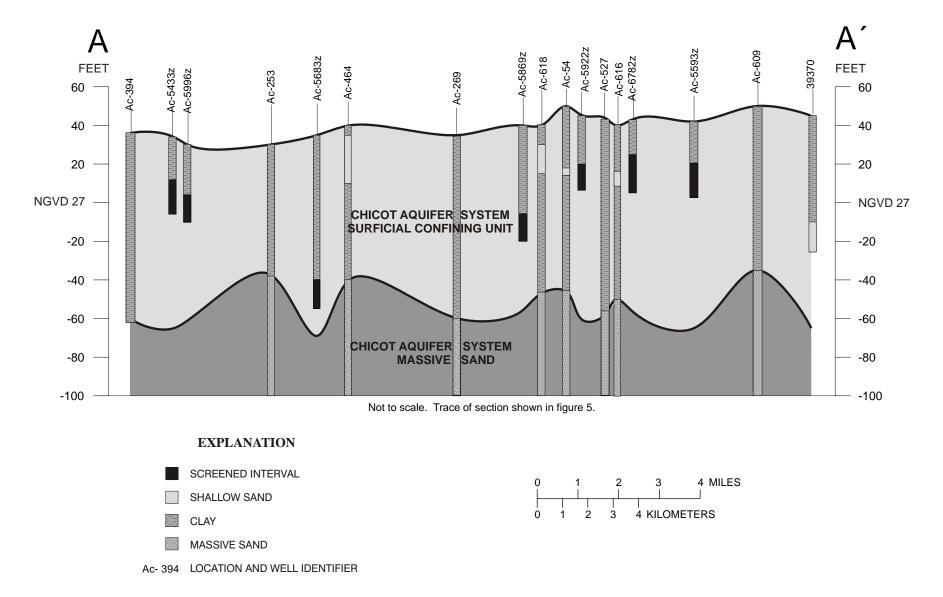


Figure 4. Generalized east-to-west hydrogeologic section in northern Acadia Parish, Louisiana.

In Acadia Parish, wells screened in shallow sands are mostly located in the northern half of the parish and are screened at depths less than 50 ft (fig. 5). Well screen depths range from 16 to 103 ft, with a mean depth of 39 ft (table 1). Five of the 80 wells had screen depths than ranged from 90 to 103 ft; the other 75 wells had screen depths that ranged from 16 to 40 ft. Approximately 9 percent of the 344 selected well logs, which were distributed throughout the parish, showed shallow sands. Well logs showing shallow sands also were mostly in the northern half of the parish.

In Allen Parish, six wells screened in shallow sands are clustered in the Oakdale area. Well screens for all the shallow wells are less than 50 ft deep (fig. 6). Well screen depths range from 17 to 40 ft, with a mean depth of 27 ft (table 1). Of 101 well logs distributed throughout the parish, only 7 percent had shallow sands. These well logs appear to be randomly distributed throughout the parish.

In Beauregard Parish, wells screened in shallow sands are clustered in the DeRidder area. Well screens for all the shallow wells are less than 50 ft deep (fig. 7). Well screen depths range from 14 to 46 ft, with a mean depth of 34 ft (table 1). Well logs in Beauregard Parish have a dispersed areal distribution. Only eight logs, mostly from wells located in the western half of the parish, indicate that shallow sands are present (fig. 7). The scarcity of shallow wells and well logs with shallow sands may indicate that shallow sands have a limited presence in the confining unit in Beauregard Parish.

In Calcasieu Parish, shallow wells screened in shallow sands are located throughout the parish. Well screens for the shallow wells vary in depth from less than 50 ft to greater than 200 ft in depth (fig. 8). Well screen depths range from 4 to 250 ft, with a mean depth of 63 ft (table 1). Fifty-five percent of the wells screened in shallow sands are screened at depths less that 50 ft, but there also are many wells screened between 50 and 200 ft (fig 8). Well logs showing shallow sands in Calcasieu Parish follow the areal distribution of the shallow wells - grouped in a line along the western border, clustered in the east-central part of the parish and scattered elsewhere. Of all of the parishes in the study area, Calcasieu Parish had the greatest percentage (42 percent) of logs showing shallow sands.

In Cameron Parish, shallow wells screened in shallow sands are located along the southern and northern border of the parish. Well screens for the shallow wells vary in depth from less than 50 ft to greater than 200 ft in depth (fig. 9). Well screen depth ranges from 7 to 325 ft with a mean depth of 127 ft (table 1). Well logs showing shallow sands generally are located near shallow wells screened in shallow sands. Few well logs and shallow wells are present in an east-to-west band through the middle of the parish, and it is not known whether shallow sands are present in this area.

In Evangeline Parish, wells screened in shallow sands are located in the southern half of the parish. Well screens for the shallow wells vary in depth from less than 50 ft to 100 ft in depth (fig. 10). Well screen depths range from 18 to 75 ft, with a mean depth of 35 ft (table 1). Most of the well logs with shallow sands also are located in the southern part of the parish. Few well logs and the absence of wells screened in shallow sands in the northern half of the parish indicate few shallow sands are present in that area.

In Iberia Parish, wells screened in shallow sands mostly are located in the western half of the parish. Eastern Iberia Parish is swampy and relatively uninhabited, so there are few rural domestic water-supply wells or well logs. Well screens for the shallow wells vary in depth from less than 50 ft to greater than 200 ft (fig. 11). Well screen depths range from 13 to 270 ft, with a mean depth of 86 ft. Well logs showing shallow sands often were located near shallow wells.

In Jefferson Davis Parish, wells screened in shallow sands are located along the southern, southwestern, and eastern borders of the parish and are absent from the south-central and northern parts of the parish. Well screens for the shallow wells vary in depth from less than 50 ft to greater than 200 ft (fig. 12). Well screen

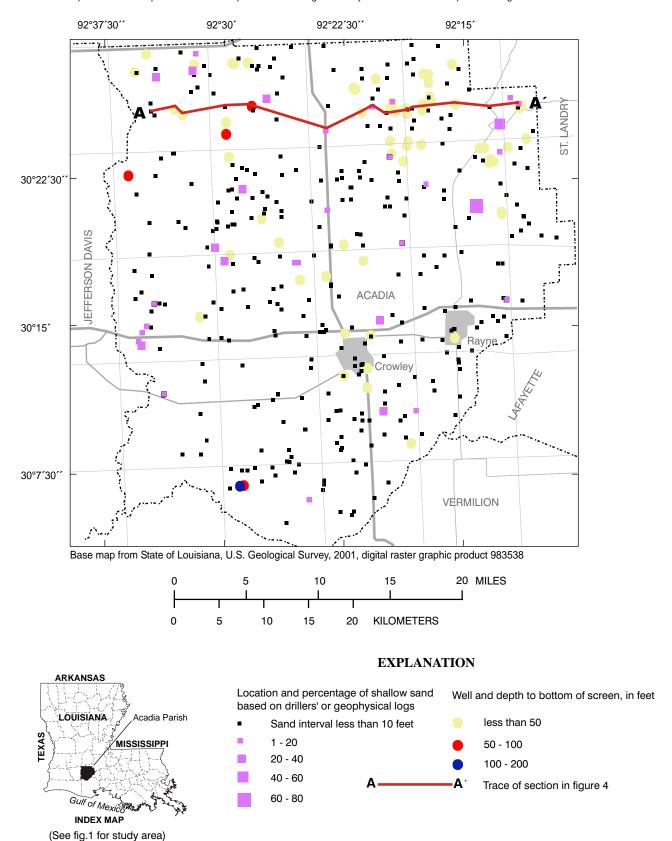


Figure 5. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in Acadia Parish, southwestern Louisiana.

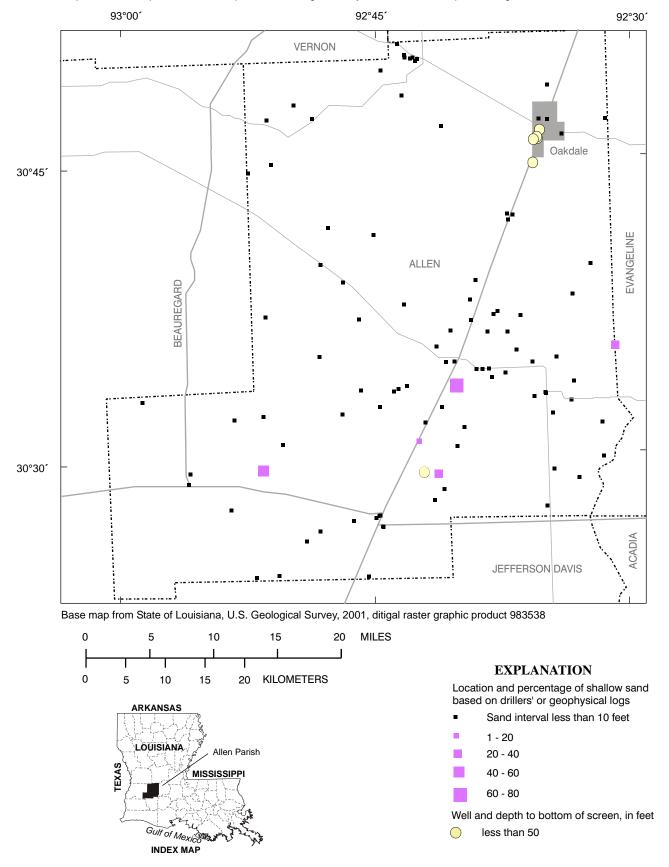


Figure 6. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in Allen Parish, southwestern Louisiana.

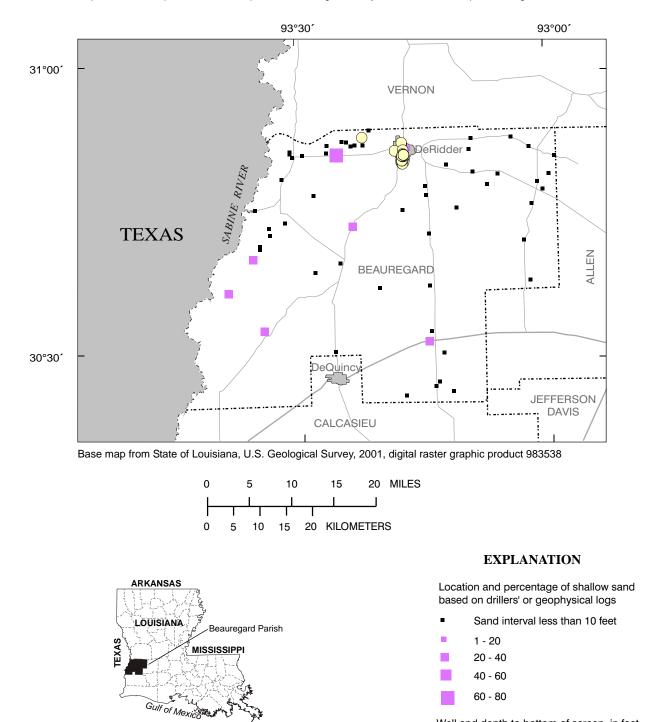
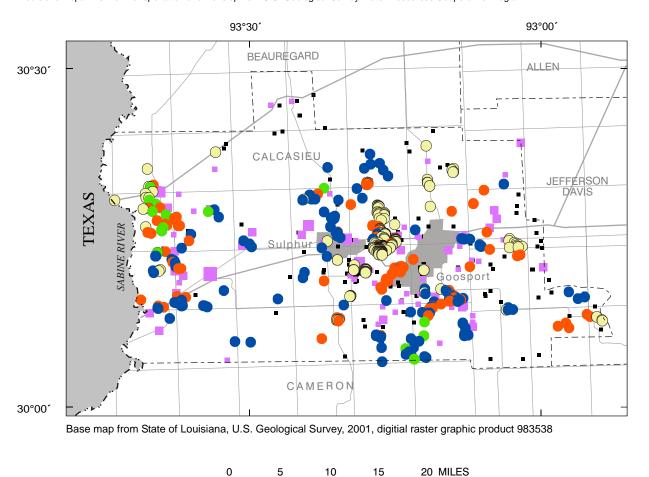


Figure 7. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in Beauregard Parish, southwestern Louisiana.

INDEX MAP

Well and depth to bottom of screen, in feet

less than 50



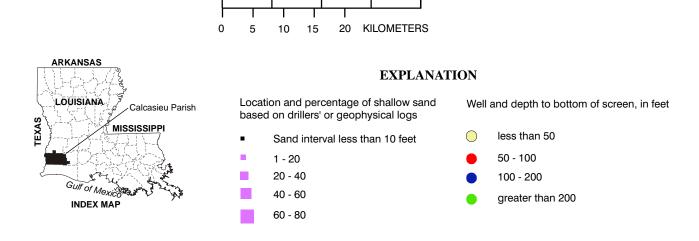
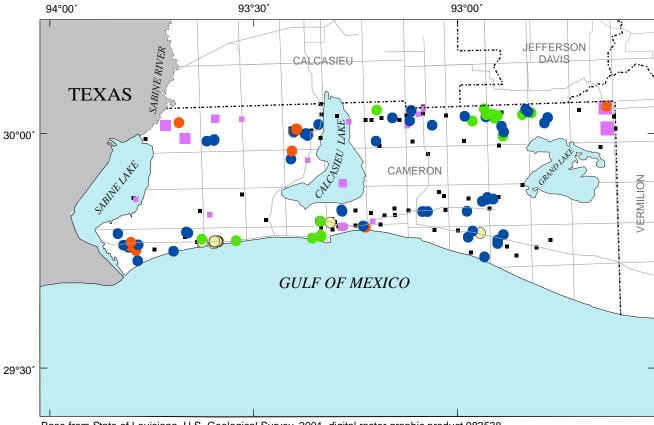
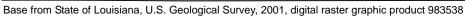
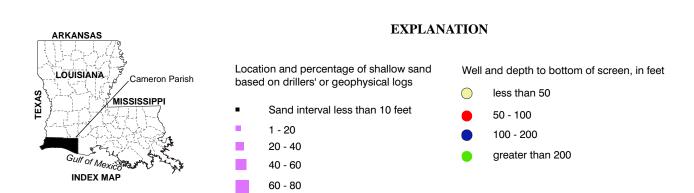


Figure 8. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in Calcasieu Parish, southwestern Louisiana.







10 15 20 KILOMETERS

20 MILES

Figure 9. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in Cameron Parish, southwestern Louisiana.

18

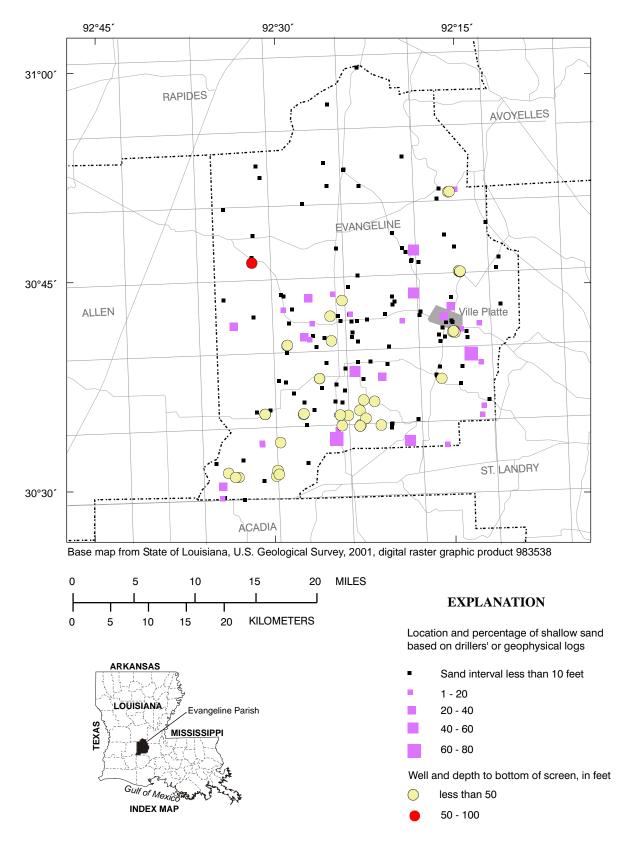
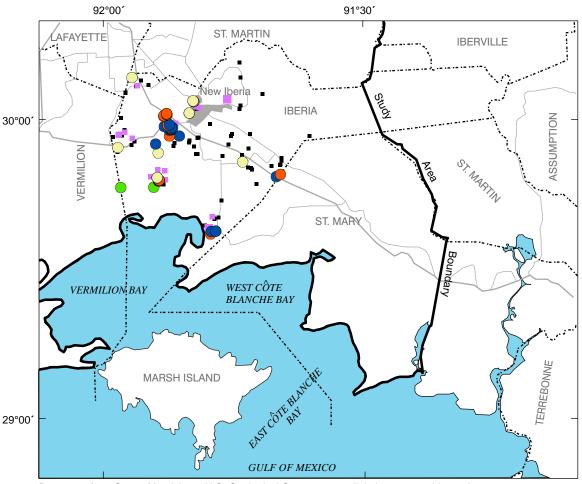
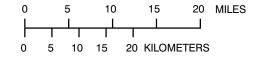


Figure 10. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in Evangeline Parish, southwestern Louisiana.



Base map from State of Louisiana, U.S. Geological Survey, 2001, digital raster graphic product 983538



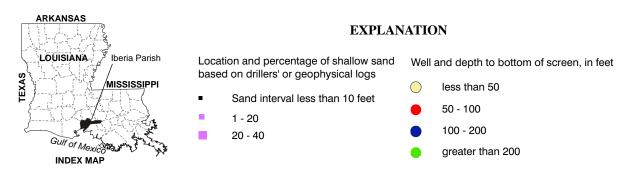


Figure 11. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in Iberia Parish, southwestern Louisiana.

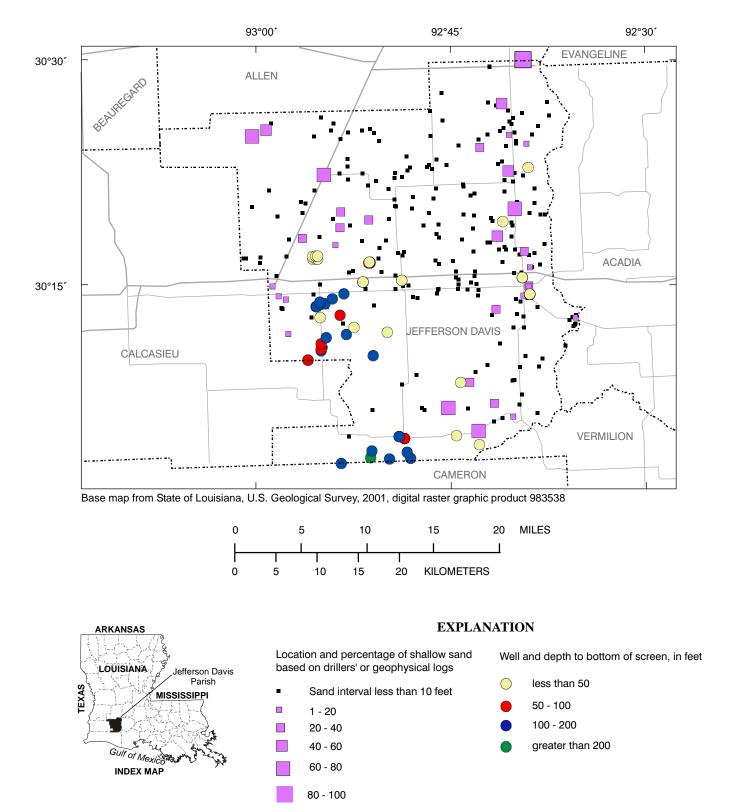


Figure 12. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in Jefferson Davis Parish, southwestern Louisiana.

depths range from 11 to 210 ft, with a mean depth of 66 ft (table 1). Well logs showing shallow sands generally are located along the eastern and southern boundaries and in the northwestern corner of the parish. Shallow sands were notably absent on logs from the central and north-central parts of the parish.

In Lafayette Parish, wells screened in shallow sands are at depths less than 50 ft in the eastern and central parts of the parish, but are mostly screened between 50 and 100 ft in the western part of the parish (fig. 13). Two wells show a screen depth in the 100 to 200 ft range. Well screen depths range from 5 to 116 ft, with a mean depth of 36 ft (table 1). Well logs were evenly distributed throughout the parish, but generally only showed shallow sands in the southeastern and western parts of the parish.

In St. Landry Parish, wells screened in shallow sands are generally located in the southwestern part of the parish. Well screens for the shallow wells vary in depth from less than 50 ft to 200 ft (fig. 14). Well screen depths range from 12 to 110 ft, with a mean depth of 27 ft (table 1). Well logs are evenly distributed throughout the parish, but generally shallow sands only are evident in the western half of the parish. The logs indicate that percentage of the confining unit composed of shallow sands is highest in St. Landry Parish and averages about 36 percent (table 1).

In St. Mary Parish, wells screened in shallow sands are located in that part of the parish which is in the study area, the western half. Well screens for the shallow wells vary in depth from less than 50 ft to greater than 200 ft (fig. 15). Well screen depths range from less than 10 to 326 ft, with a mean depth of 183 ft (table 1). Little fresh ground water is available in the southern parts of St. Mary Parish (Harder and others, 1967, pl. 5), so rural domestic water-supply and petroleum rig-supply wells are generally located in the western half of the parish. Well logs that showed shallow sands generally are located in the northwestern part of the parish.

In Vermilion Parish, wells screened in shallow sands are mostly located in the eastern part of the parish. Well screens for the shallow wells vary in depth from less than 50 ft to greater than 200 ft (fig. 16). Well screen depths range from 12 to 350 ft, with a mean depth of 98 ft (table 1). Because much of western and southern Vermilion Parish is marshy and uninhabited, most wells and well logs are located in the northeastern part of the parish (fig. 16). Many of the 61 logs indicate that shallow sands compose more than 60 percent of the surficial confining unit in this area.

SUMMARY AND CONCLUSIONS

Southwestern Louisiana is located within the Gulf Coastal Plain physiographic province. The area is underlain by thick multilayered sequences of unconsolidated sedimentary deposits that alternate between gravel, sand, silt, and clay and have a predominant dip to the south. The sand and gravel deposits form productive aquifer units and they, along with adjoining clay and silt deposits, are designated as the Chicot aquifer system. The Chicot aquifer system underlies an area of approximately 9,000 square miles in southwestern Louisiana and is the principal source of fresh ground water in the region. The dense surficial clays that confine the upper sands of the Chicot aquifer system are known as the Chicot aquifer system surficial confining unit.

Although the confining unit may be relatively uniform in composition across large areas, interbedded sands of varied areal extent and thickness are present within the confining unit. These sands are collectively known as the shallow sands of the Chicot aquifer system. The shallow sands occur irregularly throughout the confining unit and may provide sufficient water for small-diameter wells that supply water for domestic, irrigation, or petroleum rig-supply purposes.

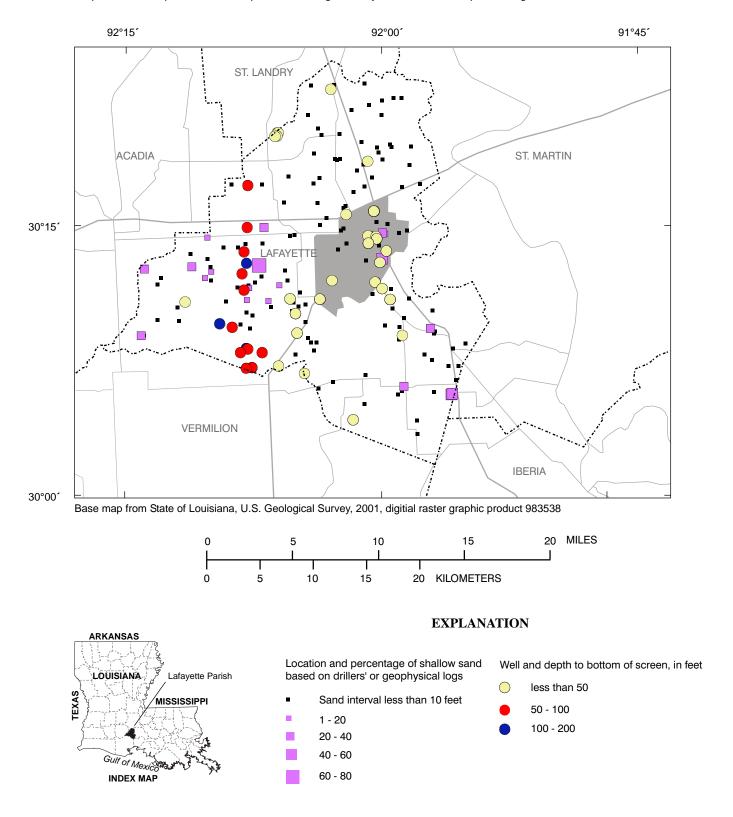


Figure 13. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in Lafayette Parish, southwestern Louisiana.

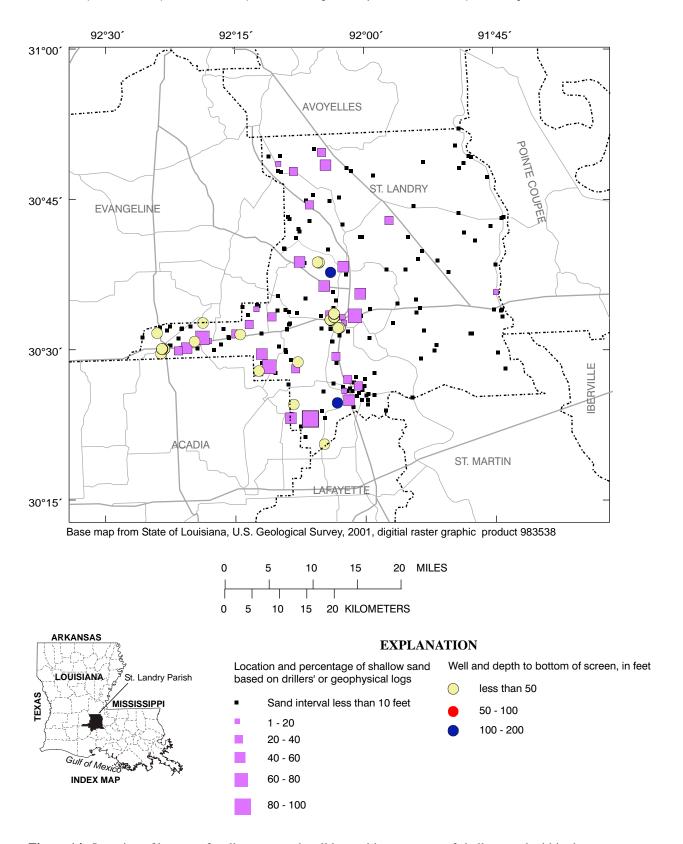
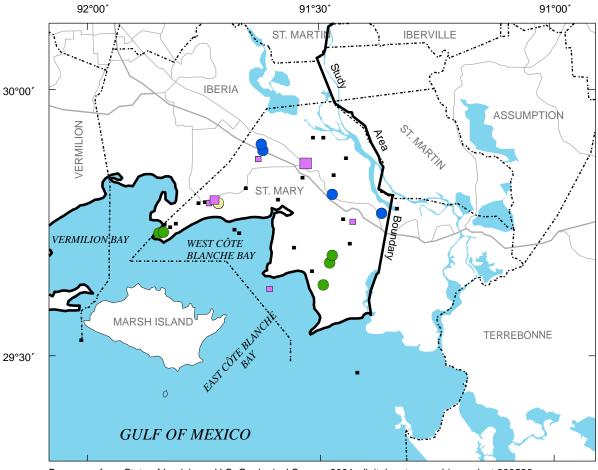
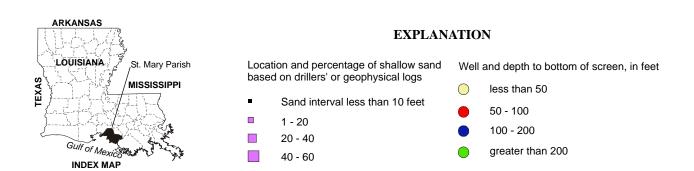


Figure 14. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in St. Landry Parish, southwestern Louisiana.



Base map from State of Louisiana, U.S. Geological Survey, 2001, digital raster graphic product 983538



15 20 KILOMETERS

20 MILES

Figure 15. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in St. Mary Parish, southwestern Louisiana.

25

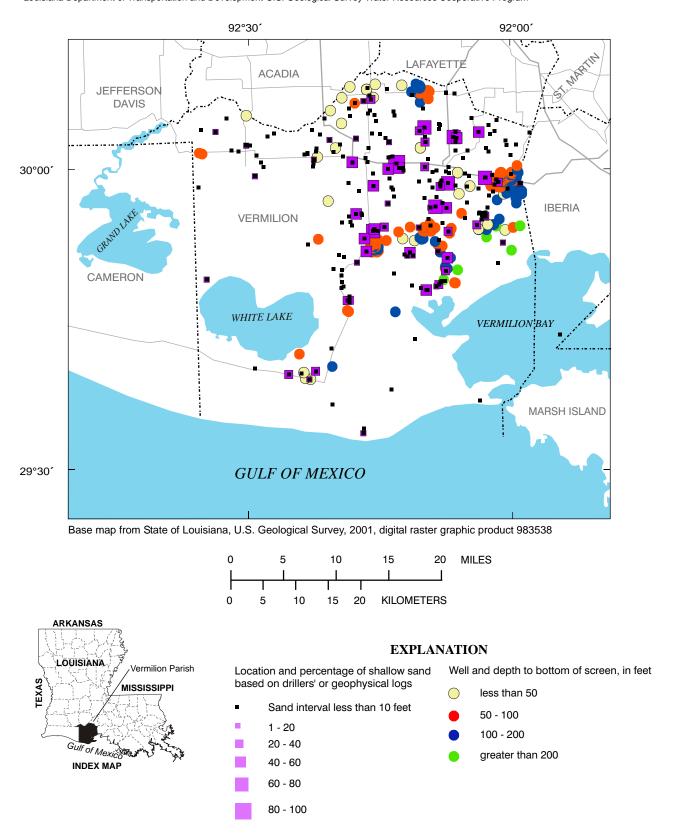


Figure 16. Location of bottom of well screens and well logs with percentage of shallow sand within the Chicot aquifer system surficial confining unit in Vermilion Parish, southwestern Louisiana.

Drillers' logs, geophysical logs, and information from shallow wells were used to define the thickness of the confining unit and locate areas of shallow sands. The thickness of the surficial confining unit generally increases from north to south. In southern Vernon and Rapides Parishes, where the Chicot aquifer system crops out, the confining unit typically is less than 40 feet thick. The thickness of the confining unit generally increases southward, and generally ranges in thickness from 160 to 400 feet in coastal parishes with a maximum thickness of about 520 feet in Vermilion and St. Mary Parishes. Because the quality of the drillers' logs varies, an analytical methodology was developed to identify the best drillers' logs and integrate higher-quality information from other sources, such as published reports.

The presence of shallow sands was documented in 12 of the 15 parishes in the study area. Welllog data from Vernon, Rapides, and St. Martin Parishes showed no shallow sands greater than 10 ft in thickness. Location and depth information of water-supply wells screened in shallow sands within the confining unit complemented the well log information with respect to the areal distribution of shallow sands. The screen depths ranged from 4 to 350 ft, and the maximum mean screen depth in a parish was 183 ft. Well location and depth to bottom of screen of the wells were mapped for the 12 parishes where shallow sands are present. The location of well logs with greater than a 10 ft sand interval and the percent shallow sand within the confining unit also were mapped for the 12 parishes in the study area. The locations of wells screened within the surficial confining unit and drillers' or geophysical logs showing shallow sands greater than 10 feet thick are mapped for 12 of the 15 parishes in the study area. The percentage of shallow-sand thickness in the confining unit is indicated for each log. Well-screen depths of 1,579 shallow wells used for domestic, irrigation, or petroleum rig-supply purposes were assumed to indicate the presence of productive shallow sands within the confining unit; however, only about 19 percent of the 2,098 logs analyzed indicate that shallow sands are present. The logs also indicate that the percentage of shallow-sand thickness in the confining unit can vary greatly across very short distances.

SELECTED REFERENCES

- Alley, W.M., 1993, Geostatistical models, *in* Alley, W.M., ed., Regional ground-water quality: New York, VanNostrand Reinhold, p. 87-108.
- Environmental Systems Research Institute, 2001, ARC/INFO Release 8.1: Redlands, Calif.
- Battaglin, W.A., Ulery, R.L., and Vowinkel, E.F., 1989, Method of simulating water-table altitudes from stream and drainage-basin locations by use of a geographic information system, *in* Mallard, G.E., and Ragone, S.E., eds., U.S. Geological Survey Toxic Substances Hydrology Program Proceedings of the technical meeting, Phoenix, Az., Sept. 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-4220, p. 531-539.
- Burrough, P.A., and McDonnell, R.A., 1998, Principles of geographical information systems: Oxford, Great Britian, Oxford University Press, p. 31-161.
- Darling, M.E., and Hubbard, L.E., 1989, Application of a geographic information system for regridding a ground-water flow model of the Columbia Plateau regional aquifer system, Walla Walla River Basin, Oregon-Washington: U.S. Geological Survey Water-Resources Investigations Report 89-4179, p. 23.
- Davis, J.C., 1973, Statistics and data analysis in Geology: New York, John Wiley and Sons, p. 381-390.
- Delhomme, J.P., 1978, Kriging in the hydrosciences: Advances in Water Resources, v. 1, no. 5, p. 251-266.
- Dunlap, L.E., and Spinazola, J.M., 1984, Interpolating water-table altitudes in west-central Kansas using kriging techniques, 1984: U.S. Geological Survey Water-Supply Paper 2238, p. 1-19.

- Frink, J.W., 1940, Subsurface Pleistocene of Louisiana: Louisiana Department of Conservation, Geological Bulletin no. 19, p. 367-419.
- Hanor, J.S., 1993, Effective hydraulic conductivity of fractured clay beds at a hazardous waste landfill, Louisiana Gulf Coast: Water Resources Research, v. 29, no. 11, p. 3, 691-3, 698.
- Hanson, R.T., 1996, Postaudit of head and transmissivity estimates and ground-water flow models of Avra Valley, Arizona: U.S. Geological Survey Water-Resources Investigations Report 96-4045, p. 84.
- Harder, A.H., 1960, The geology and ground-water resources of Calcasieu Parish, Louisiana: U.S. Geological Survey Water-Supply Paper 1488, 102 p.
- Harder, A.H., Kilburn, Chabot, Whitman, H.M., and Rogers, S.M., 1967, Effects of ground-water withdrawals on water levels and saltwater encroachment in southwestern Louisiana: Department of Conservation, Louisiana Geological Survey, and Louisiana Department of Public Works Water Resources Bulletin no. 10, 56 p.
- Holland, W.C., Hough, L.W., and Murray, G.E., 1952, Geology of Beauregard and Allen Parishes: Louisiana Department of Conservation and Louisiana Geological Survey, Geological Bulletin no. 27, 224 p.
- Howe, H.V., Russel, R.J., McGuirt, J.H., Craft, B.C., and Stephenson, M.B., 1935, Reports on the Geology of Cameron and Vermilion Parishes: Louisiana Department of Conservation and Louisiana Geological Survey, Geological Bulletin no. 6, 242 p.
- Jenks, G.F., 1963, Generalization in statistical mapping: Annuals of the Association of American Geographers, v. 53, p. 15-26.
- Jones, P.H., Turcan, A.N., Jr., and Skibitzke, H.E., 1954, Geology and ground-water resources of southwestern Louisiana: Louisiana Department of Conservation Bulletin no. 30, p. 285.
- Jones, P.H., Hendricks, E.L., Irelan, Burdge, and others, 1956, Water resources of southwestern Louisiana: U.S. Geological Survey Water-Supply Paper 1364, 460 p.
- Kniffen, F.B. and Hilliard, S.B., 1988, Louisiana, its land and people: Baton Rouge, La., Louisiana State University Press, 213 p.
- Lovelace, J.K, 1991, Water use in Louisiana, 1990: Louisiana Department of Transportation and Development Water Resources Special Report no. 6, 131 p.
- Lovelace, J.K, 1999, Distribution of saltwater in the Chicot aquifer system of southwestern Louisiana, 1995-96: Louisiana Department of Transportation and Development Water Resources Technical Report no. 66, 61 p.
- Lovelace, J.K., and Lovelace, W.M., 1995, Hydrogeologic unit nomenclature and computer codes for aquifers and confining units in Louisiana: Louisiana Department of Transportation and Development Water Resources Special Report no. 9, 12 p.
- Meyer, R.R., 1953, Summary of ground-water conditions in southwestern Louisiana: U.S. Geological Survey Open-File Report, 7 p.
- Nyman, D.J., 1984, The occurrence of high concentrations of chloride in the Chicot aquifer system of south-western Louisiana: Louisiana Department of Transportation and Development, Office of Public Works Water Resources Technical Report no. 33, 75 p.
- Nyman, D.J., 1989, Quality of water in freshwater aquifers in southwestern Louisiana: Louisiana Department of Transportation and Development Water Resources Technical Report no. 42, 22 p.

- Nyman, D.J., Halford, K.J., and Martin, Angel, Jr., 1990, Geohydrology and simulation of flow in the Chicot aquifer system of southwestern Louisiana: Louisiana Department of Transportation and Development Water Resources Technical Report no. 50, 58 p.
- Puente, C.E., and Bras, R.L., 1986, Disjunctive kriging, universal kriging, or no kriging--small sample results with simulated fields: Mathematical Geology, v. 18, no. 3, p. 287-305.
- Sargent, B.P., 2002, Water use in Louisiana, 2000: Louisiana Department of Transportation and Development Water Resources Special Report no. 15, 133 p.
- Sargent, B.P., Frederick, C.P., Roberts, F.C., 2004, Thickness data for the Chicot aquifer system surficial confining unit: Louisiana Department of Transportation and Development Water Resources Basic Records Report no. 22, 91 p.
- Saucier, R.T., 1994, Geomorphology and Quaternary geologic history of the Lower Mississippi Valley: U.S. Army Corps of Engineers, v. 1, 364 p.
- Saucier, R.T., and Snead, J.I., comps., 1989, Quaternary geology of the Lower Mississippi Valley: Baton Rouge, La., Louisiana Geological Survey, 2 sheets.
- Smoot, C.W., 1986, Areal extent of freshwater in major aquifers in Louisiana: U.S. Geological Survey Water-Resources Investigations Report 86-4150, 1 sheet.
- Sophocleous, M.A., Paschetto, J.E., and Olea, R.A., 1982, Ground-water network design for northwest Kansas, using the theory of regionalized variables: Ground Water, v. 20, no. 1, p. 48-58.
- Spruill, T.B., and Candela, Lucila, 1990, Two approaches to design of monitoring networks: Ground Water, v. 28, no. 3, p. 430-432.
- Stanley, T.B., Jr., and Maher, J.C., 1944, Ground-water resources of Jefferson Davis and Acadia Parishes, Louisiana: Louisiana Department of Public Works, 93 p.
- Stuart, C.G., Knochenmus, Darwin, and McGee, B.D., 1994, Guide to Louisiana's ground-water resources: U.S. Geological Survey Water-Resources Investigations Report 94-4085, 55 p.
- Trudeau, D.A., 1994, Geohydrology and the occurrence of selected chemical contaminants at a hazardous-waste disposal site, Calcasieu Parish, Louisiana, 1984-85: Louisiana Department of Transportation and Development, Water Resources Technical Report no. 53, 54 p.
- U.S. Geological Survey, 1985, National water summary 1984: United States Geological Survey Water-Supply Paper 2275, p. 229.
- Varvaro, G.G., 1957, Geology of Evangeline and St. Landry Parishes, Louisiana Department of Conservation and the Louisiana Geological Survey, Geological Bulletin no. 31, p. 295.
- Walters, D.J., 1996, Louisiana ground-water map no. 11: Potentiometric surface, 1991, and water-level changes, 1985-91, of the Chicot aquifer system in southwestern Louisiana: U.S. Geological Survey Water-Resources Investigations Report 95-4044, 2 sheets.
- Whitman, H.M., and Kilburn, Chabot, 1963, Ground-water conditions in southwestern Louisiana, 1961 and 1962, with a discussion of the Chicot aquifer in the coastal area: Department of Conservation, Louisiana Geological Survey, and Louisiana Department of Public Works Water Resources Pamphlet no.12, 32 p.
- Williams, C.B., and Duex, T.W, 1995, A hydrogeologic study of the Chicot aquifer in Lafayette Parish, Louisiana: Gulf Coast Association of Geological Societies Transactions, v. XLV, p. 165 172.

SMOOT, 1988 LOUISIANA HYDRAULIC ATLAS MAP NO. 3 ALTITUDE OF THE BASE OF THE FRESHWATER IN LOUISIANA

For additional information

Baton Rouge, Louisiana 70896

Telephone: (504) 389-0281

U.S. Geological Survey P.O. Box 66492

District Chief

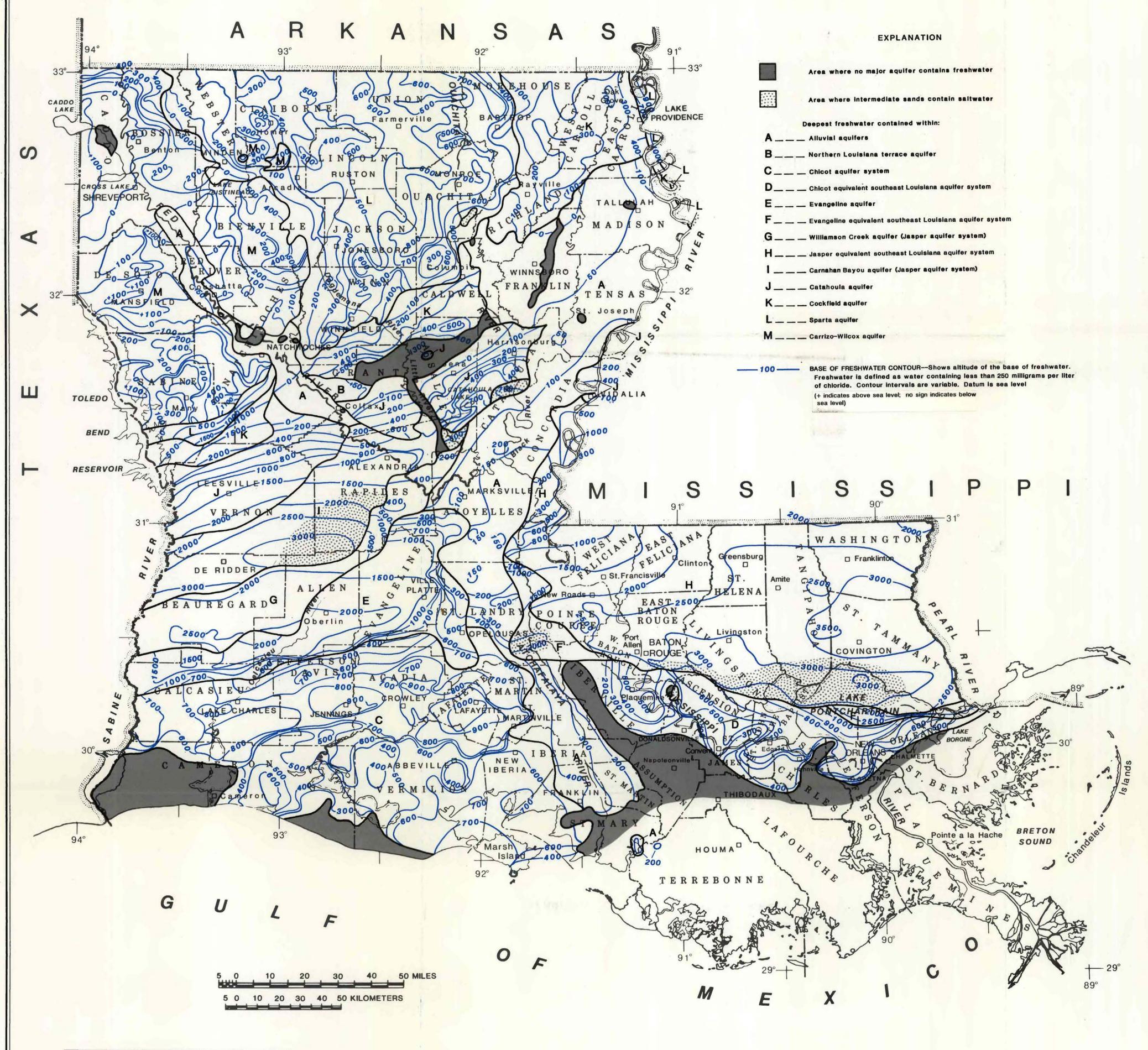
Copies of this report can be

U.S. Geological Survey Map Distribution

Denver, Colorado 80225

Box 25286

Federal Center, Bldg. 810



LOUISIANA HYDROLOGIC ATLAS MAP NO. 3: ALTITUDE OF THE BASE OF FRESHWATER IN LOUISIANA

> Charles W. Smoot 1988

INTRODUCTION

A map showing the base of fresh ground water in Louisiana was first prepared by Rollo in 1960. With subsequent investi-gations and the collection of additional data, the need to update Rollo's map became apparent. In 1984 the U.S. Geological Survey began a cooperative investigation with the Louisiana Department of Transportation and Development to refine knowledge of the base of fresh ground water in Louisiana.

This map defines the altitude of the base of freshwater in Louisiana, shows areas where no major aquifer contains freshwater, and also shows areas where sands that contain saltwater in intermediate zones between deep zones of freshwater and land surface are found.

Freshwater, for this report, is defined as water that contains a chloride concentration of less than 250 milligrams per liter. Water that contains this concentration of chloride meets the U.S. Environmental Protection Agency secondary drinking water standards (U.S. Environmental Protection Agency, 1979).

Data for this map were obtained from recently published maps by interpretation of electric-resistivity logs of water and oil wells. (For method of calculation of water quality from wells. (For method of calculation of water quality from electrical logs, see Turcan, 1966.) Map data from some recent studies were modified for this map, and map data from parts of the base-of-freshwater maps by Harder and others (1967), Whiteman (1972), Rogers (1981), and Ryals (1982) were used unmodified. Data from approximately 2,000 electric-resistivity logs were used for this project. More than 1,000 of these logs were from test water wells drilled by the Louisiana Department of Transportation and Development and the U.S. Geological Survey. Water-quality analyses from many of the test water wells confirmed the interpretation of the electrical logs. The majority of the electrical logs used for this map were made during the past 20 years. However, a few of the logs used were made over 40 years ago. However, a few of the logs used were made over 40 years ago.

The major aguifer that contains the deepest freshwater of each area is contoured individually. As most major aquifers are separated from each other by thick clay intervals, the base of freshwater may change abruptly. For example, in northern Vernon Parish, where the base of freshwater changes from within the Cockfield aquifer to within the Catahoula aquifer, the base of freshwater changes approximately 1,500 ft (feet) within 1 mi (mile). South of Baton Rouge, the base of freshwater changes more than 2,000 ft in less than 5 mi. Each aquifer is identified on this map, accompanied by contour lines showing the altitude of the base of freshwater. These areas do not represent the total areal extent of the respective aquifer, but only the area where the deepest freshwater occurs in that respective aquifer.

The contours for this map have variable intervals but generally are on 100-foot intervals above or below sea level to a depth of 1,000 ft. For depths 1,000 ft below sea level, the contour interval is 500 ft. To show detail in the area where the base of freshwater is within the shallow alluvial aquifers in northern Louisiana, a contour interval of 50 ft is used. In gray areas, none of the major aquifers contains freshwater. To obtain the maximum depths of freshwater below land surface where the altitude of freshwater occurrence is above sea level, subtract this value from land surface elevation. Where the occurrence of the altitude of freshwater is below sea level, add the value to the land-surface elevation.

BASE OF FRESHWATER

The depth to the base of freshwater is highly variable. Freshwater can be found as deep as 3,500 ft below sea level in southeastern Louisiana, but fresh ground water cannot be found at any depth in a few parts of the State.

Some areas that recently contained freshwater may now contain saltwater. For example, pumping wells near the downdip limit of freshwater within a sand causes saltwater to move laterally toward the center of pumping. If the wells are close to the saltwater front, they may yield water of increasing salinity. Pumping from the upper part of a sand in the transition zone will cause saltwater to move vertically toward the well and saltwater may eventually contaminate the well the well, and saltwater may eventually contaminate the well.

In some areas, the only fresh ground water occurs in shallow aquifers. Locally these shallow aquifers have been contaminated by saltwater introduced during the drilling of oil and gas wells by upward movement from deep saline aquifers through open boreholes, and by oil and gas related evaporation ponds. Once the contaminated saltwater moves into the aquifer, it flows very slowly downdip toward natural discharge areas or toward pumping contains. centers. Thus the areas of contaminated freshwater may change

In places, saltwater-bearing sands may occur in intermediate zones between the deep zones and shallow zones of freshwater. The areas where sands contain saltwater in intermediate zones are shown on the map by dot patterns. Within the areas mapped as shown on the map by dot patterns. Within the areas mapped as having intermediate zones of saltwater, most of the interval may contain saltwater, and an isolated, deep, freshwater-bearing sand may be the basis for contouring. For example, the only freshwater in a test well in St. John the Baptist Parish is in two intervals, 545 to 595 ft and 2,830 to 3,045 ft. All other intervening sands contain saltwater. In other areas, the intermediate saltwater may occur in only one sand above the lowermost freshwater-bearing sand. For example, the only intermediate saltwater-bearing sand in an oil-test well in Rapides Parish is from 920 to 1,080 ft. All other sand beds between land surface and a depth of 2,090 ft contain freshwater.

SELECTED REFERENCES

Cardwell, G.T., Forbes, M.J., Jr., and Gaydos, M.W., 1967, Water resources of the Lake Pontchartrain area, Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works Water Resources Bulletin 12, 105 p.

Cardwell, G.T., and Rollo, J.R., 1960, Interim report on ground-water conditions between Baton Rouge and New Orleans, Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works Water Resources Pamphlet 9, 44 p. Harder, A.H., Kilburn, Chabot, Whitman, H.M., and Rogers, S.M., 1967, Effects of ground-water withdrawals on water levels and salt-water encroachment in southwestern Louisiana: Louisiana Department of Conservation and Louisiana Department of Public

Department of Conservation and Louisiana Department of Public Works Water Resources Bulletin 10, 56 p.

Long, R.A., 1965, Ground water in the Geismar-Gonzales area, Ascension Parish, Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works Water Resources Bulletin 7, 67 p.

Payne, J.N., 1968, Hydrologic significance of the lithofacies of the Sparta Sand in Arkansas, Louisiana, Mississippi, and

Texas: U.S. Geological Survey Professional Paper 569-A, 17 p.
-- 1970, Geohydrologic significance of lithofacies of the Cockfield Formation of Louisiana and Mississippi and of the Yegua Formation of Texas: U.S. Geological Survey Professional Paper

Formation of Texas: U.S. Geological Survey Florescence 569-B, 14 p.

---- 1975, Geohydrologic significance of lithofacies of the Carrizo Sand of Arkansas, Louisiana, and Texas and the Meridian Sand of Mississippi: U.S. Geological Survey Professional Paper 569-D, 11 p.
Rogers, J.E., 1981, Water resources of the Kisatchie well-field

Rogers, J.E., 1981, Water resources or the Kisatchie Well-field area near Alexandria, Louisiana: Louisiana Department of Transportation and Development, Office of Public Works Water Resources Technical Report 26, 57 p.

Rogers, J.E., Calandro, A.J., and Gaydos, M.W., 1972, Water resources of Ouachita Parish, Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works

Water Resources Bulletin 14, 118 p.
Rollo, J.R., 1960, Ground water in Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works

Water Resources Bulletin 1, 84 p.

- 1966, Ground-water resources of the greater New Orleans area, Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works Water Resources Bulletin

9, 69 p. Ryals, G.N., 1982, Ground-water resources of the Arcadia-Minden Ryals, G.N., 1982, Ground-water resources of the Arcadia-Minden area, Louisiana: Louisiana Department of Transportation and Development, Office of Public Works Water Resources Technical Report 28, 35 p.

Turcan, A.N., Jr., 1966, Calculation of water quality from electrical logs-theory and practice: Department of Conservation, Louisiana Geological Survey, and Louisiana Department of Public Works Water Passurces Pamphlet 19, 23 p.

of Public Works Water Resources Pamphlet 19, 23 p.

U.S. Environmental Protection Agency, 1979, National secondary drinking water regulations, Office of Drinking Water, 37 p. Whiteman, C.D., Jr., 1972, Ground water in the Plaquemine-White Castle area, Iberville Parish, Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works Water Resources Bulletin 16, 69 p.

Whitfield, M.S., Jr., 1975 [1976], Geohydrology of the Evangeline and Jasper aquifers of southwestern Louisiana: Louisiana Department of Conservation and Louisiana Department of Public Works Water Resources Bulletin 20, 72 p.

Works Water Resources Bulletin 20, 72 p.
Winner, M.D., Jr., 1963, The Florida Parishes--an area of large,

undeveloped ground-water potential in southeastern Louisiana:
Louisiana Department of Public Works, 50 p.
Winner, M.D., Jr., Forbes, M.J., Jr., and Broussard, W.L., 1968,
Water resources of Pointe Coupee Parish, Louisiana: Louisiana Department of Conservation and Louisiana Department of
Public Works Water Resources Bulletin 11, 110 p.
Winslow, A.G., Hillier, D.E., and Turcen, A.M., Jr., 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066, 1066,

Winslow, A.G., Hillier, D.E., and Turcan, A.N., Jr., 1968 [1969], Saline ground water in Louisiana: U.S. Geological Survey Hydrologic Investigations Atlas HA 310.

STOLPER, K., 1994 CALCULATE A MORE ACCURATE WATER SALINITY BY VISUALLY ELIMINATING "M"

Calculate a More Accurate Water Saturation by Visually Estimating "m"

by Kathy Stolper Stolper Geologic, Inc.

Water saturation calculations derived from wireline log responses have historically assumed "m" = 2 when "m" (the cementation exponent) is unknown. This practice can lead to erroneously high values for water saturation, and possibly by-passed pay, since there are many instances where "m" is less than 2

The Archie "m" can be measured in the laboratory, but this is an expensive (\$300-\$500 per sample) and time-consuming process. Also, rotary core plugs are required for the analysis. Measurement cannot be obtained with cuttings or sidewall core samples. A quicker and less expensive alternative (and the only alternative if rotary core plugs are unavailable) is to estimate "m" by comparing your samples to rocks with known "m" values. Rather than assuming "m" = 2, a more accurate estimate can be made to more accurately calculate water saturation.

Visual evaluation of cuttings, sidewall core, and/or whole core using a binocular microscope at 20X to 50X magnification will allow you to describe the many features of a rock which affect Archie "m". Once these features have been described, an accurate estimate of "m" can be made.

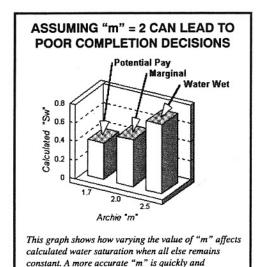
Pattern recognition skills are useful for visually estimating Archie "m" since it is based on the familiarization of rock comparators which have measured "m" values. The comparators referred to here can be the ones supplied to members of the Shell Rock Catalog, or similar ones which companies make for their private use. Once a frame of reference has been established for rocks with measured "m", estimates can be made for rocks with unknown "m". An accurate visual estimate of Archie "m" ultimately requires practice and patience. The best way to acquire this skill is through the use of rock comparators.

The cementation exponent "m" is related to the pore geometry of the rock; therefore, it is extremely important that you view a dry, freshly broken surface for this examination.

The effects on "m" can be said to be associated with the concept of order versus disorder. That is, the more orderly the pore geometry of a rock, the lower the value of "m"; conversely, the more disorderly the pore geometry, the higher the "m" value.

The cementation exponent can vary from 1.2 to 2.2 for sandstones, and can be as high as 3.1 for carbonates. The following is a list of factors which can influence "m" (if the porosity remains unchanged), along with the reasons for their impact on "m":

- An increase in grain sorting decreases "m" since the pore geometry becomes more orderly.
- 2. An increase in cement increases "m" because the pore geometry becomes more disorderly.
- 3. An increase in compaction increases "m" because pore throats are cut off, thus isolating pores.
- 4. An increase in "patchy" cement increases "m" due to the breaks in net electrical continuity.
- A decrease in grain size increases "m" because the surface area to grain volume increases.
- Bimodality increases "m" because the pore geometry becomes more disorderly.
- 7. An increase in the amount of interconnected vugs increases "m" because the pore geometry becomes more disorderly.
- 8. An increase in the amount of clay increases "m" because the surface area to grain volume increases. Some clay types will have more of an effect than others because of the variation in cation exchange capacities (CEC). The greater the CEC, the greater the conductivity,



inexpensively estimated from visual rock analysis. This

greatly increases your chances for success.

the lesser the effect on "m". The commonly encountered clay minerals in order of increasing CEC and decreasing effect on the value of "m" are: kaolinite with CEC of 3 to 15, chlorite and illite with CEC of 10 to 40, and smectite with CEC of 80 to 150.

 For carbonates, "m" is affected by particle size, interparticle porosity, and vuggy porosity (isolated and interconnected).

All of these contributing factors are visible features of the rock and can be used to visually estimate Archie "m". Cuttings are a readily available source from which an accurate and inexpensive estimate of "m" can be made. The more accurate the "m", the more accurate the water saturation calculation, which ultimately leads to a reduced danger of bypassing pay.

For more information contact the author at 16688 W 73rd Drive

Arvada, CO 80007 303-674-3100 www.stolpergeologic.com

USGS, 2017 WATER RESOURCES OF CALCASIEU PARISH, LOUISIANA





Prepared in cooperation with the Louisiana Department of Transportation and Development

Water Resources of Calcasieu Parish, Louisiana

Introduction

Information concerning the availability, use, and quality of water in Calcasieu Parish, Louisiana (fig. 1), is critical for proper water-resource management. The purpose of this fact sheet is to present information that can be used by water managers, parish residents, and others for stewardship of this vital resource. Information on the availability, past and current use, use trends, and water quality from groundwater and surfacewater sources in the parish is presented. Previously published reports (see References Cited section) and data stored in the U.S. Geological Survey's National Water Information System (http://dx.doi.org/10.5066/F7P55KJN) are the primary sources of the information presented here.

In 2010, about 223.7 million gallons per day (Mgal/d) of water were withdrawn in Calcasieu Parish, including about

136.7 Mgal/d from surface-water sources and 87.0 Mgal/d from groundwater sources.¹ Withdrawals for industrial use accounted for the majority (156.5 Mgal/d) of total water withdrawn (tables 1–2). Other categories of use included public supply, power generation, rural domestic, livestock, rice irrigation, general irrigation, and aquaculture. Water-use data collected at 5-year intervals from 1960 to 2010 (fig. 2) indicated that water withdrawals peaked in 1970 at about 1,020 Mgal/d. The generally downward trend in water withdrawals from 1960 to 2010 is largely attributable to reductions in withdrawals for industrial use and rice irrigation.

¹Water-withdrawal data are based on estimated or reported site-specific data and aggregated data, which are distributed to sources. For a full description of water-use estimate methodology, see "Data Collection" in Sargent (2011). Tabulation of numbers in text and tables may result in different totals because of rounding; nonrounded numbers are used for calculation of totals.

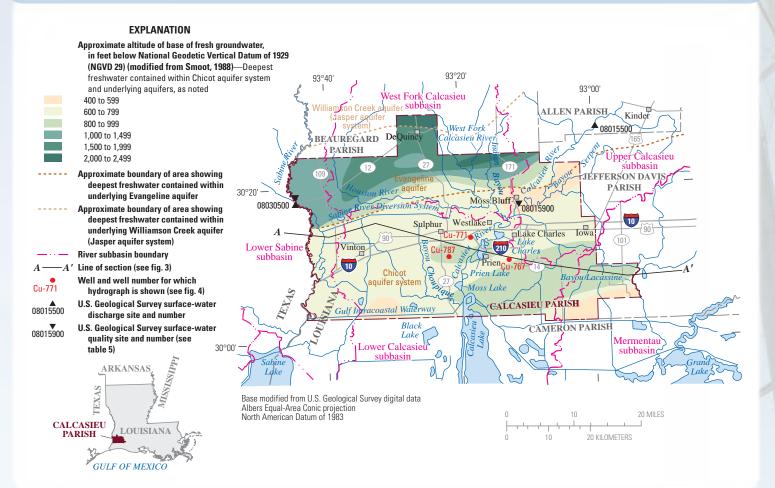


Figure 1. Location of study area, Calcasieu Parish, Louisiana.

Table 1. Groundwater withdrawals, in million gallons per day, by source and use category in Calcasieu Parish, Louisiana, 2010 (B.P. Sargent, U.S. Geological Survey, written commun., 2015).

[<, less than]

Use category		Evenueline					
	"200-foot" and upper sand	"500-foot" sand	"700-foot" and lower sand	Undifferentiated sand	Shallow sand	Evangeline aquifer	Total by use
Public supply	1.19	21.62	2.10	0.04	0.00	0.79	25.73
Industrial	1.16	39.35	< 0.01	0.72	0.00	0.00	41.23
Power generation	0.00	6.46	0.00	0.00	0.00	0.00	6.46
Rural domestic	1.56	0.53	0.00	0.02	0.11	0.00	2.23
Livestock	0.10	0.03	0.01	0.04	0.01	0.00	0.20
Rice irrigation	3.71	2.29	0.63	0.95	0.32	0.00	7.90
General irrigation	0.18	0.11	0.02	0.00	0.03	0.00	0.34
Aquaculture	0.58	0.58	0.58	0.00	1.16	0.00	2.90
Total by source	8.49	70.97	3.35	1.77	1.63	0.79	87.00

Table 2. Surface-water withdrawals, in million gallons per day, by source and use category in Calcasieu Parish, Louisiana, 2010 (B.P. Sargent, U.S. Geological Survey, written commun., 2015).

Use category	Calcasieu River	Gulf Intracoastal Waterway	Sabine River Diversion System	Miscellaneous streams	Total by use
Public supply	0.00	0.00	0.50	0.00	0.50
Industrial	76.17	0.01	39.12	0.00	115.30
Power generation	0.05	0.00	14.46	0.00	14.51
Livestock	0.00	0.00	0.00	0.30	0.30
Rice irrigation	0.00	0.00	0.00	3.77	3.77
Aquaculture	0.00	0.00	0.00	2.34	2.34
Total by source	76.22	0.01	54.07	6.42	136.72

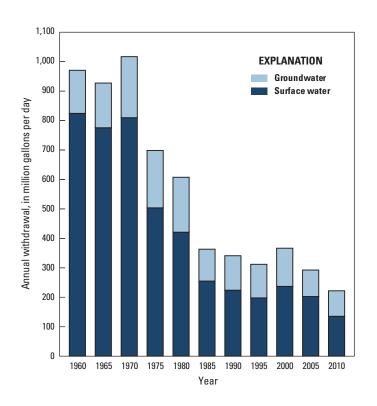


Figure 2. Water withdrawals in Calcasieu Parish, Louisiana, 1960–2010 (Sargent, 2011).

Groundwater Resources

Fresh groundwater (water with a chloride concentration of 250 milligrams per liter [mg/L] or less) is available in Calcasieu Parish in several different aquifers to varying depths, depending on location. The base of freshwater in Calcasieu Parish ranges from about 400 feet (ft) below the National Geodetic Vertical Datum of 1929 (NGVD 29) to almost 2,500 ft below NGVD 29. The deepest freshwater is north of DeQuincy within the Williamson Creek aquifer. In the rest of the roughly northern quarter of the parish, the base is present at depths from about 700 to 2,000 ft or more below NGVD 29 within the Evangeline aquifer. In the southern three-fourths of the parish, the base of freshwater ranges in depth from about 500 to 800 ft below NGVD 29 and is within the Chicot aquifer system (fig. 1; Smoot, 1988).

The Chicot Aquifer System

The Chicot aquifer system is an important regional aquifer system underlying most of southwestern Louisiana. The aquifer system crops out and receives recharge in parishes to the north and northeast of Calcasieu Parish where the aquifer system is largely composed of one, major, undifferentiated sand. The undifferentiated sand thickens and deepens to the south and, near the northern border of Calcasieu Parish (fig. 1), becomes subdivided into a complex series of sand layers by clay confining layers. West of about the

longitude of the town of Iowa (fig. 1), these divisions consist of the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area (fig. 3). East of this longitude, these divisions consist of the Chicot aquifer upper and lower sands, which are hydraulically connected to the "200-foot" and "700-foot" sands, respectively (fig. 3).

A surficial confining layer of clay restricts infiltration of precipitation into the groundwater system throughout the parish. The surficial confining layer thickness ranges from 40 ft in small areas in northwestern and northeastern Calcasieu Parish to 280 ft in the south-central part of the parish (Sargent, 2004). Within the surficial confining clay are scattered sand streaks, sand lenses, and sand layers collectively named the "shallow sand unit of the Chicot aquifer system."

The primary aquifers in the parish are the "200-foot," "500foot," and "700-foot" sands (table 1), and these aquifers share similar characteristics but are present at varying depths. The "200-foot" sand generally grades from fine to medium sand at the top to a coarse sand or gravel at the base (Harder, 1960). The top of the sand is present at depths of zero to 50 ft above NGVD 29 near the northeastern corner of the parish and greater than 300 ft below NGVD 29 in the southwestern corner of the parish (Harder, 1960). The "500-foot" sand generally grades from fine sand at the top to coarse sand and gravel near the base (Harder, 1960). The top of the "500-foot" sand is present at less than 400 ft below NGVD 29 in northern areas of the parish and reaches over 600 ft below NGVD 29 in the southeastern corner of the parish (Nyman, 1984). The base of the "500-foot" sand ranges from greater than 400 ft below NGVD 29 in the northern part of the parish to greater than 800 ft below NGVD 29 in the southeastern corner of the parish (Nyman, 1989). The "700-foot" sand is generally tan to grayish and grades from fine sand at the top to coarse sand at the base (Harder, 1960). The top of the "700-foot" sand is present at depths of less than 400 ft below NGVD 29 in the northern part of the parish and reaches depths exceeding 800 ft below NGVD 29 in the southeastern corner of the parish. The base of the lower sand and "700-foot" sand ranges from greater than 400 ft in the northern tip of the parish to greater than 1,000 ft in the southeastern corner of the parish (Nyman, 1989). In 2015, more than 4900 active wells were screened in Chicot aquifer system in Calcasieu Parish, with most of them being screened in these three primary aquifers from depths of 13 to 849 ft, with yields of up to 5,471 gallons per minute (Louisiana Department of Natural Resources, written commun., 2015) (table 3).

Water levels in wells in all three sands in Calcasieu Parish showed similar spatial and temporal patterns. In 2011–12, water levels in wells screened in the "200-foot," "500-foot," and "700-foot" sands in Calcasieu Parish ranged from highs of approximately 7.6 ft above, 2.4 ft below, and 14.1 ft below NGVD 29, respectively, to lows of 49.9 ft below, 79.6 ft below, and 69.6 ft below NGVD 29, respectively (U.S. Geological Survey, 2016a). Spatially, water levels in wells in all three sands were lowest near the Calcasieu River in the Lake Charles metropolitan area, corresponding well to the documented movement of groundwater toward this area (Nyman, 1984; Lovelace, 1998). Water levels in wells have varied in similar ways over time and have risen in general by as much as 20 ft since the 1970s (fig. 4), because of decreased pumping.

Groundwater Quality

Freshwater samples collected from 111 wells screened in the "200-foot" sand, 239 wells screened in the "500-foot" sand, and 63 wells screened in the "700-foot" sand had median hardness values in the moderately hard range.² Over 90 percent of samples in each aquifer did not exceed the U.S. Environmental Protection Agency's Secondary Maximum Contaminant Levels (SMCLs)³ for pH. Over 80 percent of samples in each aquifer did not exceed the SMCL for dissolved-solids concentrations. Median values for iron concentrations were below the SMCL in the "200-foot" sand and greatly exceeded the SMCL in the "500-foot" and "700-foot" sands (table 4).

Saltwater (water with a chloride concentration greater than 250 mg/L) is present in both local and widespread areas within the Chicot aquifer system in Calcasieu Parish. At the base of the "200-foot" sand and in the upper sand, saltwater is present along most of the southern parish boundary, in the southeastern corner of the parish, and in a localized area near Iowa. At the base of the

³The SMCLs are nonenforceable Federal guidelines regarding cosmetic effects (such as tooth or skin discoloration) or aesthetic effects (such as taste, odor, or color) of drinking water. At high concentrations or values, health implications as well as aesthetic degradation might exist. SMCLs were established as guidelines for the States by the U.S. Environmental Protection Agency (2016).

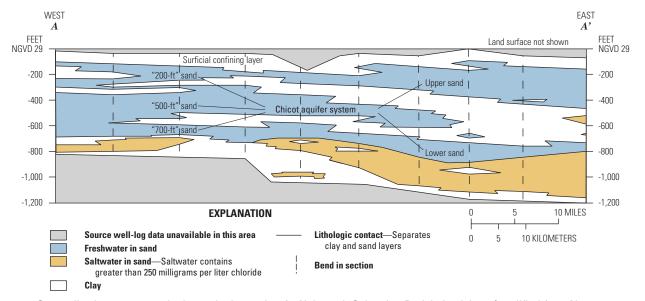


Figure 3. Generalized west-to-east hydrogeologic section A–A' through Calcasieu Parish, Louisiana (modified from Nyman, 1984). Trace of section shown on figure 1.

²Hardness ranges, expressed as milligrams per liter of calcium carbonate, are as follows: 0–60, soft; 61–120, moderately hard; 121–180, hard; greater than 180, very hard (Hem, 1985).

Table 3. Active registered wells in the Chicot aquifer system in Calcasieu Parish in 2015 (Louisiana Department of Natural Resources, written commun., 2015).

	Shallow sand	"200-foot" and upper sands	"500-foot" sand	"700-foot" and lower sands	Undifferentiated sand
Domestic	276	2,985	935	15	20
Industrial	5	35	121	12	4
Irrigation	17	120	93	16	7
Public supply	7	142	120	13	4
Power generation	0	0	6	0	0
Total	305	3,282	1,275	56	35
Well depth range (feet	12 205	10.500	120 740	445.040	70.460
below land surface)	13–305	18–590	130–740	445–849	70–460
Yield range (gallons per minute)	2–50	4–5,471	5-5,000	20–4,700	30–4,000

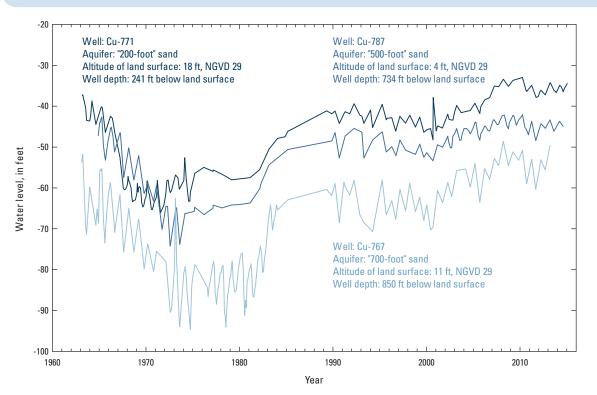


Figure 4. Water levels in wells Cu-771, Cu-787, and Cu-767 screened in the "200-foot" sand, "500-foot" sand of the Chicot aquifer system in Calcasieu Parish, Louisiana (see fig. 1 for well locations; U.S. Geological Survey, 2016a). Land surface and water levels are in feet (ft) relative to the National Geodetic Vertical Datum of 1929 (NGVD 29).

"500-foot" sand, saltwater is present along much of the southern parish boundary, in the southeastern corner of the parish, and in three small isolated areas at or near industrial facilities between Lake Charles and Sulphur. At the base of the "700-foot" sand and in the lower sand, saltwater is present in the southern two-thirds of the parish. The "700-foot" sand contains only saltwater along most of the southern parish boundary (Harder, 1960; Nyman, 1989).

Surface-Water Resources

Surface-water resources in Calcasieu Parish are available in two regional drainage basins: the Calcasieu-Mermentau Basin (Hydrologic Unit Code [HUC] 080802), which covers the majority of the parish, and the Sabine Basin (HUC 120100), which is present along the Sabine River on the western side of the parish (U.S. Geological Survey, 2016b). In 2010, about 136.7 Mgal/d of surface water were withdrawn in Calcasieu Parish for public supply, industry, power generation, livestock, rice irrigation, and aquaculture use (table 2). Over 95 percent of surface-water withdrawals came from

the Calcasieu River (76.22 Mgal/d) and Sabine River Diversion System (54.07 Mgal/d) (table 2).

Calcasieu-Mermentau Basin

The Calcasieu-Mermentau Basin is subdivided into six subbasins, four of which are present in Calcasieu Parish. These subbasins are the West Fork Calcasieu (HUC 08080205), Upper Calcasieu (HUC 08080203), Lower Calcasieu (HUC 08080206), and Mermentau (HUC 08080202) (fig. 1).

The West Fork Calcasieu and Upper Calcasieu subbasins cover most of the northern half of the parish and drain south into the Lower Calcasieu subbasin, which extends to and drains southward into the Gulf of Mexico. The West Fork Calcasieu subbasin is drained by the Houston River, West Fork Calcasieu River, Indian Bayou, and many other small streams. The Houston River and Indian Bayou are tributaries of West Fork Calcasieu River, which flows into the Calcasieu River just upstream of Lake Charles. The Upper Calcasieu

Table 4. Summary of selected water-quality characteristics of freshwater in the Chicot aquifer system in Calcasieu Parish, Louisiana (U.S. Geological Survey, 2016a).

[Values are in milligrams per liter, except as noted. °C, degrees Celsius; PCU, platinum cobalt unit; µS/cm, microsiemen per centimeter; SU, standard unit; CaCO₃, calcium carbonate; µg/L, microgram per liter; NA, not applicable; SMCL, Secondary Maximum Contaminant Level established by the U.S. Environmental Protection Agency (2016)]

	Temper- ature (°C)	Color, (PCU)	Specific conductance, field (µS/cm at 25°C)	pH, field (SU)	Hardness (as CaCO ₃)	Chloride, filtered (as Cl)	Iron, filtered (μg/L as Fe)	Manga- nese, filtered (µg/L as Mn)	Dissolved solids, filtered
		"200-fo	ot" sand of the Lak	ke Charles a	rea, 1940–200	9 (111 wells)			
Median	22.0	1	483	7.5	110	32	230	140	280
10th percentile	20.3	0	364	6.9	66	16	30	60	232
90th percentile	23.3	10	1,090	7.9	200	120	2,800	450	509
Number of samples	79	28	95	68	73	106	46	48	63
Percentage of samples that do not exceed SMCLs	NA.	93	NA	93	NA	100	59	6	86
		"500-fo	ot" sand of the Lak	ke Charles a	rea, 1940–200	6 (239 wells)			
Median	23.5	5	404	7.2	110	34	1,000	350	258
10th percentile	22.0	0	301	6.8	80	22	180	240	214
90th percentile	25.0	20	677	7.6	140	98	2,200	480	436
Number of samples	127	99	188	143	155	237	97	91	104
Percentage of samples that do not exceed SMCLs	NA.	87	NA	99	NA	100	19	1	92
		"700-	foot" sand of the L	ake Charles	area, 1939–95	(63 wells)			
Median	24.0	5	548	7.4	100	68	920	390	332
10th percentile	22.0	0	341	6.7	66	26	260	160	263
90th percentile	25.5	36	952	8.2	140	200	2,100	500	558
Number of samples	32	29	49	40	46	62	15	20	30
Percentage of samples that do not exceed SMCLs	NA.	72	NA	92	NA	100	13	0	83
				SMCLs					
	NA	15	NA	6.5-8.5	NA	250	300	50	500

subbasin is drained by the Calcasieu River whose tributaries include Bayou Serpent and many other small streams. The annual average discharge upstream of Calcasieu Parish for the Calcasieu River near Kinder (site number 08015500) (fig. 1) during 1922–2014 was 2,524 cubic feet per second (ft³/s) (U.S. Geological Survey, 2016a) from a drainage area of 1,700 square miles (mi²). The Lower Calcasieu subbasin in Calcasieu Parish contains the Calcasieu River, Bayou Choupique, the Gulf Intracoastal Waterway, and many other small streams. Multiple lakes are found along the Calcasieu River in Calcasieu Parish.

The Mermentau subbasin is located in the southeastern corner of the parish and is drained by Bayou Lacassine and other small streams.

Sabine Basin

The Sabine Basin contains only the Lower Sabine subbasin in Calcasieu Parish (HUC 12010005) and is drained by the Sabine River. The Sabine River drains a strip of land along the western border of

the parish and is connected to the interior of Calcasieu Parish by canals. In the north-central part of the parish, the Sabine River Diversion System conveys water by way of canal from the Sabine River eastward to several industries located near Westlake and Sulphur. The system also supplies water for municipal use and irrigation (Sabine River Authority, 2007). In the southern part of the parish, the Gulf Intracoastal Waterway runs roughly east-west from the Texas border, across the Calcasieu River just south of Moss Lake, then southeastward into Cameron Parish. The annual average discharge of the Sabine River near Ruliff, Tex. (site number 08030500), (fig. 1) during 1961–2015 was 7,626 ft³/s from a drainage area of about 9,330 mi² (U.S. Geological Survey, 2016a).

Surface-Water Quality

Water samples collected from the Calcasieu River near Lake Charles (site number 08015900) during 1968–78 and from the Sabine River near Ruliff, Tex., during 1967–2000 have median

hardness values in the soft range (table 5). Over 80 percent of samples did not exceed the SMCL for iron concentrations, and median pH values were also within the SMCLs. Dissolved-oxygen concentrations were generally greater than 5 mg/L, which is considered the minimum value for a diverse population of fresh, warmwater biota, including sport fish (Louisiana Department of Environmental Quality, 2008).

References Cited

- Harder, A.H., 1960, The geology and ground-water resources of Calcasieu Parish, Louisiana: U.S. Geological Survey Water-Supply Paper 1488, 102 p., accessed December 6, 2012, at http://pubs.er.usgs.gov/publication wsp1488.
- Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 264 p., accessed February 20, 2013, at http://pubs.er.usgs.gov/publication/vsp2254.
- Louisiana Department of Environmental Quality, 2008, Environmental Regulatory Code, Title 33, Part IX, Subpart 1: Baton Rouge, Louisiana Department of Environmental Quality, accessed June 9, 2009, at http://www.deq.louisiana.gov/portal/tabid/1674/Default.aspx.
- Lovelace, J.K., 1998, Distribution of saltwater in the Chicot aquifer system in the Calcasieu Parish area, Louisiana, 1995-96: Louisiana Department of Transportation and Development Water Resources Technical Report no. 62, 59 p.
- Nyman, D.J., 1984, The occurrence of high concentrations of chloride in the Chicot aquifer system of southwestern Louisiana: Louisiana Department of Transportation and Development, Office of Public Works Water Resources Technical Report no. 33, 75 p.
- Nyman, D.J., 1989, Quality of water in freshwater aquifers in southwestern Louisiana: Louisiana Department of Transportation and Development Water Resources Technical Report no. 42, 22 p., 28 pls.
- Sabine River Authority, 2007, Diversion canal history: Sabine River Authority, accessed September 26, 2011, at http://12.6.56.180/index.php?q=content/history-0.
- Sargent, B.P., 2004, Thickness of the Chicot aquifer system surficial confining unit and location of shallow sands, southwestern Louisiana: Louisiana Department of Transportation and Development Water Resources Technical Report no. 73, 29 p.

- Sargent, B.P., 2011, Water use in Louisiana, 2010: Louisiana Department of Transportation and Development Water Resources Special Report no. 17, 135 p.
- Smoot, C.W., 1988, Louisiana hydrologic atlas map no. 3—Altitude of the base of freshwater in Louisiana: U.S. Geological Survey Water-Resources Investigations Report 86–4314, 1 sheet, accessed November 2, 2011, at http://pubs.er.usgs.gov/publication/wri864314.
- U.S. Environmental Protection Agency, 2016, Secondary Drinking Water Standards: Guidance for Nuisance Chemicals, accessed April 13, 2016, at https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals.
- U.S. Geological Survey, 2016a, National Water Information System—Web interface: Accessed January 28, 2016, at http://waterdata.usgs.gov/nwis.
- U.S. Geological Survey, 2016b, Science in Your Watershed: U.S. Geological Survey Web page, accessed May 18, 2016, at http://water.usgs.gov/wsc/reg/08.html.

This fact sheet was published by the U.S. Geological Survey in cooperation with the Louisiana Department of Transportation and Development.

By Vincent E. White and Lawrence B. Prakken

For additional information, contact:

Director, USGS Lower Mississippi-Gulf Water Science Center 3535 S. Sherwood Forest Blvd., Suite 120

Baton Rouge, LA 70816

E-mail: gs-w-lmg center director@usgs.gov

Fax: (225) 298–5490 Telephone: (225) 298–5481

Home Page: http://la.water.usgs.gov

Table 5. Summary of selected water-quality characteristics for the Calcasieu and Sabine Rivers, Calcasieu Parish, Louisiana (U.S. Geological Survey, 2016a).

[Values are in milligrams per liter, except as noted. μ S/cm, microsiemen per centimeter; °C, degrees Celsius; SU, standard unit; CaCO₃, calcium carbonate; μ g/L, microgram per liter; SMCL, Secondary Maximum Contaminant Level established by the U.S. Environmental Protection Agency (2016); NA, not applicable]

	Specific conductance, field (µS/cm at 25°C)	Oxygen, dissolved	pH, field (SU)	Hard- ness (as CaCO ₃)	Calcium, filtered (as Ca)	Magne- sium, filtered (as Mg)	Sodium, filtered (as Na)	Chloride, filtered (as Cl)	Sulfate, filtered (as SO ₄)	Iron, filtered (μg/L as Fe)
		С	alcasieu Ri	ver near Lak	ce Charles, 19	68–78¹				
Median	98	7.4	6.7	18	4.2	1.7	12	18	6.0	140
10th percentile	43	5.4	5.8	10	2.5	0.8	4.3	5.1	3.7	80
90th percentile	3,360	10.0	7.2	330	26	65	520	980	130	360
Number of samples	49	48	49	49	49	49	49	49	49	15
Percentage of samples that do not exceed SMCLs	NA	NA.	69	NA	NA	NA	NA.	86	94	87
		;	Sabine Rive	r near Ruliff	, Texas 1967—	2000²				
Median	142	7.8	6.8	29	7.4	2.4	15	18	12	150
10th percentile	92	6.4	6.2	18	4.9	1.3	9.2	11	7.2	70
90th percentile	197	10.2	7.2	38	10	3.3	21	27	19	360
Number of samples	538	190	302	291	291	291	213	520	519	106
Percentage of samples that do not exceed SMCLs	NA	NA.	80	NA	NA	NA	NA.	100	100	87
				SMCL	S					
	NA	NA	6.5-8.5	NA	NA	NA	NA	250	250	300

¹Site number 08015900 (see fig. 1).

²Site number 08030500 (see fig. 1).

WARNER, D.L., 1988 ABANDONED OIL AND GAS INDUSTRY WELLS AND THEIR ENVIRONMENTAL IMPLICATIONS

UIPC SUMMER MEETING



UNDERGROUND INJECTION PRACTICES COUNCIL

1988 SUMMER MEETING

The Portland Marriott, Portland, Oregon

July 31-August 3, 1988

PROCEEDINGS

With

AGENDA

UIPC Headquarters Staff

Michel J. Paque, Executive Director Rosemary A. Marmen, Director of Communications Jeffrey S. Lynn, Technical Director Betty J. Robins, Administrative Assistant Vera Garland, Receptionist Clerk

UIPC/UIPC Research Foundation Headquarters 525 Central Park Drive Suite 304 Oklahoma City, OK 73105

(405) 525-6146

TABLE OF CONTENTS

		PAGE
1.	UIPC Summer Meeting Agenda	1
2.	Discussion of a Fault in Modeling Class I Hazardous Waste Injection Wells - JAMES D. GREENLES	7
3.	Acid Neutralization by Gulf Coast Sediments - LIMM E. FIME DR. WINTON AUBERT	23
4.	Oil and Gas Industry Water Injection Well Corrosion Study - TROY MICELE	47
5.	Abandoned Oil and Gas Industry Wells and Their Environmental Implications - DR. DON L. WARNER	69
6.	The Technology of NIR Logging - JOHN BERNER	91
7.	The Economic Significance of Testing Class III Wells for Mechanical Integrity Using the Dual Packer/	
	Pressure Method - DICK ORTIS	115
8.	Publications List	125
9.	Referral Form for UIPC Information and Membership	127
LO.	List of Attendees	129

ABANDONED OIL AND GAS INDUSTRY WELLS AND THEIR ENVIRONMENTAL IMPLICATIONS

· Prepared by

Dr. Don L. Warner, P.E., C.P.G. Rolla, Missouri

for the

American Petroleum Institute Washington, D.C.

February 1988

CONTENTS

ABANDONED OIL AND GAS INDUSTRY WELLS AND THEIR ENVIRONMENTAL IMPLICATIONS

- I. Summary and Conclusions
- II. Introduction
- III. Geology and Hydrology of Oil and Gas Producing Regions
 - A. General Geologic Frameworks
 - B. Groundwater Occurrence and Movement
 - C. Groundwater Chemistry
 - D. Hydrogeologic Parameters
- IV. Environmental Implications of Abandoned Wells
 - A. Properly Plugged and Abandoned Wells
 - B. Improperly Plugged and Abandoned Wells
 - 1. Exploration Wells vs. Development Wells
 - 2. Variables Affecting Contamination Potential of an Abandon
 - a. Pressure Status of the Geologic Sequence Penetrated
 - b. Abandoned Well Flow Mechanics
- V. Case Example
- VI. References

FIGURES

- Figure 1 Schematic Diagram of Interaquifer Flow Through the Borehole of an Abandoned Well
- Figure 2 Schematic Diagram of Flow to the Ground Surface Through the Borehole of an Abandoned Well
- Figure 3 Well Status Map, XYZ Field, Mississippi
- Figure 4 Generalized Stratigraphic Column XYZ Field, Mississippi
- Figure 5 Scaled Simulation Grid
- Figure 6 Detail of the Simulation Grid
- Figure 7 Increase in Pressure Along Section A-A' after 10 Years of Injection Simulation 1
- Figure 8 Increase in Pressure Along Section A-A' after 10 Years of Injection . Simulation 6

I. SUMMARY AND CONCLUSIONS

Many thousands of wells have been drilled and abandoned during the 130 year history of the U.S. petroleum industry. Regulations for plugging of such wells were nonexistent in the early days of the industry and have evolved, wells were years, to their present effective level. Thus, an unknown but large number of abandoned wells exist that are unplugged or inadequately plugged by today's standards.

As a result of incidents in which abandoned wells have been implicated as sources of ground water contamination, such wells are often considered, without discrimination among them, to be potential pathways for contamination of an underground source of drinking water (USDW). Such contamination can result from interaquifer flow of natural formation water or by transmission of injected fluids from the injection reservoir to an USDW.

In fact, the relative contamination potential of such wells ranges from highly likely to impossible, depending on a complex set of geologic and hydrologic circumstances. The relative contamination potential of an abandoned well or wells in a particular geologic and hydrologic setting can be analyzed qualitatively by an understanding of the factors involved and can be quantitatively analyzed with available numerical computer models. An example of such a model analysis is given for a case where the abandoned well is judged to not be a potential source of contamination to an USDM, even in the presence of a nearby injection well.

It can be concluded that abandoned unplugged or improperly plugged wells may or may not pose a potential for contamination to underground sources of drinking water, depending on a complex set of geologic and hydrologic circumstances. Therefore, it seems reasonable that regulation of oil and gas industry activities should take into account the wide range of contamination potential of individual abandoned wells when establishing specific operating restrictions in their vicinity.

II. INTRODUCTION

During the 130 year history of the U.S. petroleum industry hundreds of thousands of oil and gas¹ exploration and production wells have been drilled, many of which are abandoned. For many years, effective requirements for the plugging of wells upon abandonment did not exist and, thus, an unknown but very large number of unplugged or inadequately plugged wells exists in the country. Such abandoned wells have been observed to be conduits by which

1. Under the Underground Injection Control regulatory programs of the U.S. EPA, petroleum industry injection wells are defined as Class II wells.

natural formation waters and, perhaps, injected fluids have migrated between subsurface formations (Figure 1) and in some cases, to the ground surface (Figure 2). This is a particular threat where injection wells are present that increase reservoir pressures and can induce such fluid movement as is shown in Figures 1 and 2.

As a result of such known or suspected incidents involving abandoned wells, some can be expected to believe that all abandoned wells pose a contamination potential to USDW's. This paper is intended to briefly outline the circumstances under which abandoned unplugged or improperly plugged wells may and, on the other hand, may not be a pathway for contamination of an USDW. The paper will show that the circumstances that determine the extent of hazard of an abandoned well are very complex and have, only recently, become subject to analysis by computer modeling. A case example of such modeling is given in which an abandoned well is analyzed and judged to not be a threat to an USDW.

III. GEOLOGY AND HYDROGEOLOGY OF OIL AND GAS PRODUCING REGIONS

A. General Geologic Frameworks

The vast majority of oil and gas production is from sequences of sedimentary rocks that occur in geologic basin areas and range in thickness from a few thousand to over 50,000 feet. Oil and gas wells that penetrate these sedimentary rocks range from several hundred to over 20,000 feet in total depth. Types of sedimentary rocks containing oil and gas include sand and sandstone, siltstone, shale, limestone, dolomite, salt, gypsum and, occasionally, other less common ones. Sand, sandstone, limestone and dolomite are commonly porous and permeable enough to act as oil and gas producing reservoir rocks whereas siltstone, shale salt and gypsum are more likely to act as cap rocks or confining beds.

The various sedimentary rock types occur in intercalated sequences, depending on the environment in which they are deposited and the nature of the supply of the depositional material. In the United States, particular geologic basins are characterized by the rock sequences that they contain. For example, the Texas-Louisiana Gulf coastal region contains principally interbedded sand-siltstone-shale, whereas various interior basins are dominated by carbonate (limestone and dolomite) rocks with occasional sandstones and shales. These consolidated to semiconsolidated oil and gas bearing rocks are from Cambrian to Tertiary in age.

In many areas, the sedimentary rocks described above are overlain by thin layers of unconsolidated gravels, sands, silts and clays of alluvial, glacial or other origin that are of Recent or Pleistocene age and are generally fresh-water bearing.

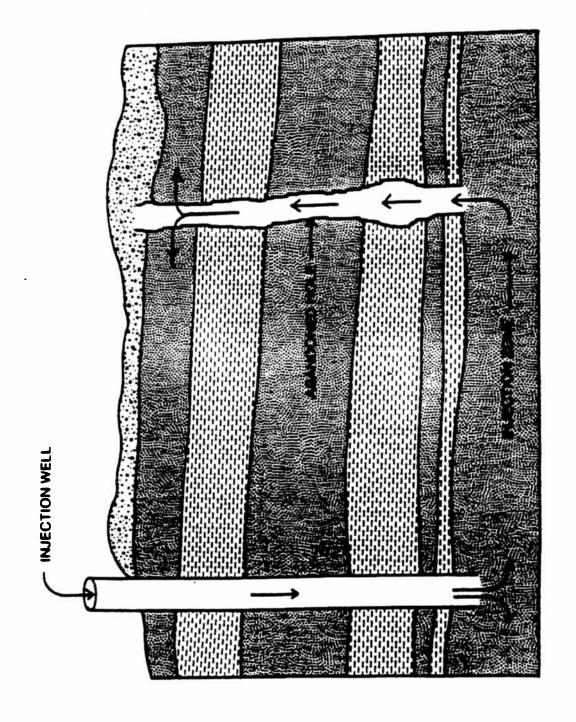


Figure 1 - Schematic diagram of interaguifer flow through the borehole of an abandoned well (Aller, 1984).

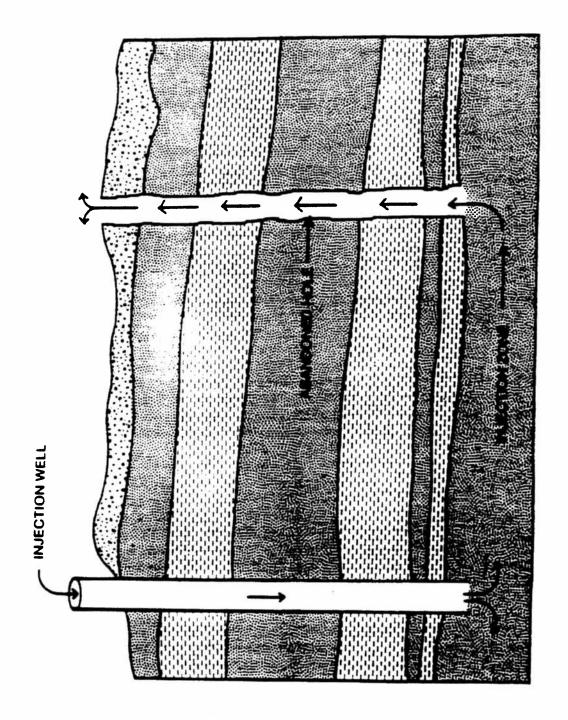


Figure 2 - Schematic diagram of flow to the ground surface through the borehole of an abandoned well (Aller, 1984).

B. Groundwater Occurrence and Movement

All soils and rocks contain water, in the subsurface. At depths of from a few feet to, at most, a few hundred feet, there is sufficient water present to completely saturate the soil or rock. The depth, at which saturation occurs is termed the ground-water table. Below that depth, all soil or rock is saturated and the contained water is termed ground water. Shallow ground water is often unconfined, that is, precipitation is able to infiltrate directly to the water table and recharge the water-containing aquifer. At greater depths, ground water becomes confined or semiconfined by the less permeable rocks in the sedimentary sequence. Oil and gas occurs and is accumulated in deep confined aquifers or reservoirs in very limited locations where structural and stratigraphic geologic conditions are favorable. All of the remaining subsurface rocks are entirely water filled.

Ground water circulates in response to the hydrologic cycle of precipitation, infiltration, recharge, ground water flow and discharge. Shallow ground water may flow relatively rapidly, as much as several feet per day, whereas very deep confined ground water may be almost stationary, flow rates being so slow as to be unmeasurable with the methodology available and in the time framework in which man operates.

In areas of relatively gentle topography, water in confined aquifers at the location of a single drilled well would rise in that well to nearly a common elevation, when adjusted for the differing density of the water in different aquifers. This condition is referred to as hydrostatic and simply means that there is little or no potential for the water to move vertically from one confined aquifer to another. In other cases, vertical equilibrium does not, naturally, exist and flow is occurring, though usually slowly, among confined aquifers. The status of the local ground water system, hydrostatic or not, is determined by drilling a borehole and measuring the level of the piezometric surface in each successively deeper aquifer by one or more of the various measurement methods available.

C. Groundwater Chemistry

The chemical quality of natural ground water is characterized by its content of the common cations, sodium, potassium, calcium and magnesium and the common anions; chloride, bicarbonate and sulfate and by the total dissolved solids comprised by these constituents. Fresh waters contain up to 1,000 mg/l of TDS, brackish waters 1,000-10,000 mg/l, saline waters 10,000-100,000 mg/l and brines greater than 100,000 mg/l of TDS.

The salinity or TDS content of a ground water is determined by its age and location and by the minerals that it has contacted during its lifetime. Young shallow waters tend to be low in TDS and deep old waters high in TDS. Often, a progressive increase in salinity occurs, with depth, in the aquifers intersected by a borehole in an oil producing area. Increased salinity also means increased density. Fresh water weighs

62.4 lb/ft³ (has a specific gravity of 1.0) whereas a brine with a TDS content of 100,000 mg/l will weigh about 66.5 lb/ft³ and have a specific gravity of 1.066. The hydrostatic pressure gradient of the fresh water would be 0.433 psi per foot of depth and of the brine would be 0.469 psi per foot of depth. An "average" hydrostatic gradient might be about 0.46 psi per foot of depth.

D. Hydrogeologic Parameters

To make quantitative assessments of ground water flow patterns and any consequent transport of contaminants in the subsurface, it is necessary to measure or estimate a number of hydrogeologic parameters or characteristics of the fluids and rocks involved. Fluid properties are density, viscosity compressibility and chemistry. Rock properties include porosity, permeablility, thickness and compressibility.

These fluid and rock properties are obtained by a variety of geologic, geophysical and engineering methods or, where not measured, are estimated. Calculations are then made with analytical equations or numerical models to analyze and predict patterns of subsurface water flow and possible associated ground water contamination.

IV. ENVIRONMENTAL IMPLICATIONS OF ABANDONED WELLS

When a borehole is drilled through a series of subsurface geologic formations that contain waters of differing chemical quality, it immediately becomes a potential pathway for movement of those waters among formations. This is one reason why wells are cased with steel casing and why cement is forced into the open area (annulus) between the casing and the wall of the borehole. It is the principal reason for the careful plugging of well bores with cement and drilling mud before well abandonment.

A. Properly Plugged and Abondoned Wells

In recent years, the Federal Government and the states have adopted increasingly stringent requirements for the methods and procedures for plugging and abandonment of oil and gas wells. It is assumed that, when wells have been plugged and abandoned under current procedures, the well-bores are sealed and do not allow movement of fluids among subsurface formations and, thus, are not potential sources of ground water contamination.

B. Improperly Plugged and Abandoned Wells

During the early history of the oil and gas industry, the potentia danger to usable ground water from abandoned unplugged or improperly

plugged oil and gas wells was not recognized and many thousands of such wells were either not plugged at all or were inadequately plugged to prevent interformational water flow. In the earliest days of the oil and gas industry, scant or no recording requirements existed and the numbers and locations of many wells abandoned during that era are unknown.

As regulation improved, well permits were required and numbers and locations are on record. The details of plugging are, however, still often unknown and it must be assumed that effective plugs were often not emplaced. Modern wells are required to have permits for drilling and for abandonment and plugging methods and procedures are carefully supervised so that abandoned plugged wells are not a hazard to ground water.

From this brief history, it can be concluded that the potential for contamination to an USDW from abandoned wells is closely related to the era during which they were constructed, the hazard being from wells drilled prior to enactment of effective plugging and abandonment regulations. An important aspect of this conclusion is that the depth to which wells are drilled has steadily increased with time. Early wells were very shallow, often only a few hundred feet but seldom more than 2,000-3,000 feet in depth. Few wells today are less than 3,000 feet in depth. This means that most wells being drilled today will not be in direct communication with many older unplugged or improperly plugged wells.

1. Exploration Wells vs. Development Wells

It is useful to distinguish among the types of wells drilled by the oil and gas industry when considering their possible contamination potential. Exploration wells are drilled outside of producing fields or are drilled to targets deeper than known production in producing fields. In either case, they are of lesser environmental concern than development wells drilled inside producing areas, since well density will be less and there is, therefore, less possiblity of interaction among wells that would lead to interformational fluid flow.

2. Variables Affecting Contamination Potential of an Abandoned Well

The variables that determine the contamination potential that an abandoned unplugged or improperly plugged well poses to underground sources of drinking water are many and complex. Let it first be said that some such abandoned wells do pose a threat to USDW's while many are believed not to, for reasons that will be examined.

a. Pressure Status of the Geologic Sequence Penetrated

In considering the potential environmental effects of unplugged or improperly plugged abandoned wells it is essential to characterized the pressure regimes that may exist in the formations penetrated by such wells. The possible detailed scenarios are too extensive for it to be practical to attempt to discuss them all. It was mentioned

earlier that reservoirs or aquifers in a geologic sequence may naturally be under hydrostatic or normally pressured conditions or may be overpressured or underpressured relative to hydrostatic conditions. Considerable debate exists over the reasons for these varying natural pressure conditions but there is no question of their existence. Superimposed upon these natural reservoir or aquifer pressure conditions are the effects of petroleum production, groundwater pumpage, oilfield brine disposal by reinjection, secondary and enhanced oil recovery projects and other man-induced effects.

Whatever the original pressure status of a gelogic sequence of aquifers and reservoirs, petroleum production will lower the original pressure of the producing reservoir so that it will often be underpressured relative to the rest of the sequence. When petroleum production ceases, the reservoir will begin to return to its original natural pressure status. The rate of this pressure recovery depends upon the geologic and engineering reservoir characteristics but should require a time period comparable to that during when the reservoir was produced. The cycle of pressure depletion and recovery of an oil field will be affected by oilfield brine reinjection for pressure maintenance by waterflooding for secondary oil recovery and by enhanced-oil-recovery projects. Ground water pumpage will affect the pressures in drinking water aquifers similarly to production of petroleum reservoirs as described above.

The variety of possible flow patterns that can occur among aquifers and reservoirs with differing pressure conditions is, thus, very extensive and the local circumstances will have be examined in order to reach a conclusion concerning the threat of an abandoned well to an USDW. For example, there is no hazard of flow from a pressure-depleted petroleum reservoir to a normally pressured water-supply aquifer. In fact, flow would be into the pressure-depleted reservoir rather than from it. Even when reservoir pressure has recovered, no threat would exist in a normally pressured sequence. A hazard only exists when a saline-water bearing aquifer or reservoir is at a higher flow potential than an overlying fresh water aquifer connected with it by an unplugged or improperly plugged abandonded well. Even in that circumstance, movement of saline water into an USDW may not occur for reasons that will be describe below.

b. Abandoned Well Flow Mechanics

Given the presence of an abandoned well that is improperly plugged or unplugged, is open to a geologic sequence of aquifers and which penetrates a petroleum producing reservoir or reservoirs, the analysis of the

potential for flow of natural saline water or injected fluids into underground sources of drinking water is a complex but tractable problem. Among the variables of the problem are:

- i. Flow potential status of all aquifers and reservoirs in the sequence penetrated by the abandoned well. This is discussed under a. above.
- Status or condition of the borehole of the abandoned well - Even though a well may have not been plugged or may have been inadequately plugged at abandonment, most boreholes will contain impediments to interaquifer fluid flow. These include drilling muds, partially effective cement or mud plugs, collapsed or sloughed formations, formations that have expanded into the borehole and, possibly, drilling equipment or well completion equipment lost in the hole. Only under unusual circumstances will abandoned wells not contain such flow impediments. possible case of that type would be a cable-tool well drilled in a sequence of competent strata in which drilling mud was not used and in which no form of plug was ever employed. Such wells probably exist in early field areas in several geologic provinces but will, typically, be shallow and not in communication with present producing formations. Probably all rotary drilled wells will contain, at least, drilling mud as a flow impediment.
- Details of the operation of petroleum or water producing iii. activities in formations intersected by the borehole -The effects of any injection and/or production wells that are completed in formations intersected by the boreholes of an abandoned well must be superimposed upon the flow gradients that exist under non-operational conditions. For example, if an abandoned well is bottomed in a ... petroleum reservoir that is undergoing waterflooding, the pressure effects of waterflood injection and production wells at the point where the abandoned well penetrates the reservoir must be determined so that the total differential pressure available to move fluids up the abandoned well is known. Effects of pumping from or injection into other aguifers must also be accounted for. For example, pumping from a fresh-water bearing aquifer would create a pressure decrease that would encourage fluid movement into that aguifer.
- iv. Subsurface geologic conditions Essential to determining the environmental hazard potential of an abandoned well is the subsurface geologic framework in the vicinity of the well. For example, if the abandoned well is drilled through formations that exhibit extreme lateral variability, the well may not be an effective pathway for

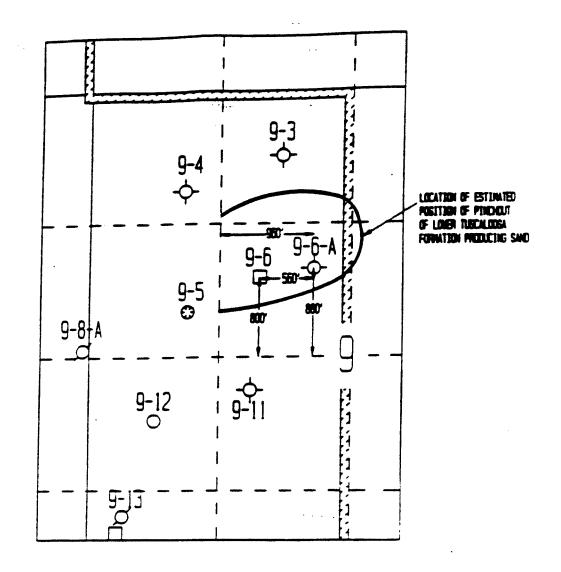
fluid movement from an oil producing formation into a fresh water aquifer because the well may miss either t petroleum producing or water yielding units in the respective formations.

v. Engineering characteristics of all units in the geolog sequence and their contained fluids - The rate of flow and flow path that will be taken by formation waters of injected fluids in response to flow gradients that exi among formations in communication through an abandoned well will depend on the engineering properties of the formations and their contained fluids. Formation properties include porosity, permeability thickness an compressibility. Fluid properties include density, viscosity and compressibility. Both formation and flu properties and the differential flow gradient are ente into the appropriate analytical equations or numerical models in order to calculate flow paths and flow quantities. Such calculations are an accepted means (modeling subsurface flow problems and provide relative practical means of evaluating hazard of an abandoned well.

Y. CASE EXAMPLE

The case example that will be described is based on a recent unpublish study of the possible environmental effects of an abandoned well located may a proposed water injection well. The wells are located in an oilfield undergoing an enhanced oil recovery project in Mississippi. Figure 3 shows portion of the oilfield with the two wells studied. Well 9-6 is the propose water injection well. Well 9-6A is the abandoned well. The producing same for the oilfield pinches out by facies change to the north, east and south the two wells, as shown in Figure 3. Figure 4 shows a generalized stratigraphic column for the field. The Lower Tuscaloosa Sand is the producing sand for the field. It occurs at a depth of 10,490 feet in well and is 26 feet thick. The base of the deepest underground source of drink water occurs at a depth of 3100 feet, in sands of the Sparta Formation, whis about 700 feet thick.

The predicted hydraulic effects in abandoned well 9-6A resulting from proposed injection into Well 9-6 were studied with a numerical model, SWIF III (Ward, 1987). SWIFT III is a revised and improved version of a code originally developed for the U.S. Geological Survey specifically for injectively modeling. The original code and its successors have received extensiverification, validation and use. Figure 5 depicts the finite difference used in the simulations. Figure 6 is another representation of the grid showing the line of cross-section A-A', which is used to display the result of selected simulations.



XYZ FIELD MISSISSIPPI

WELL STATUS JULY 1987

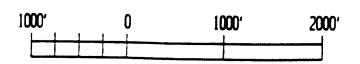
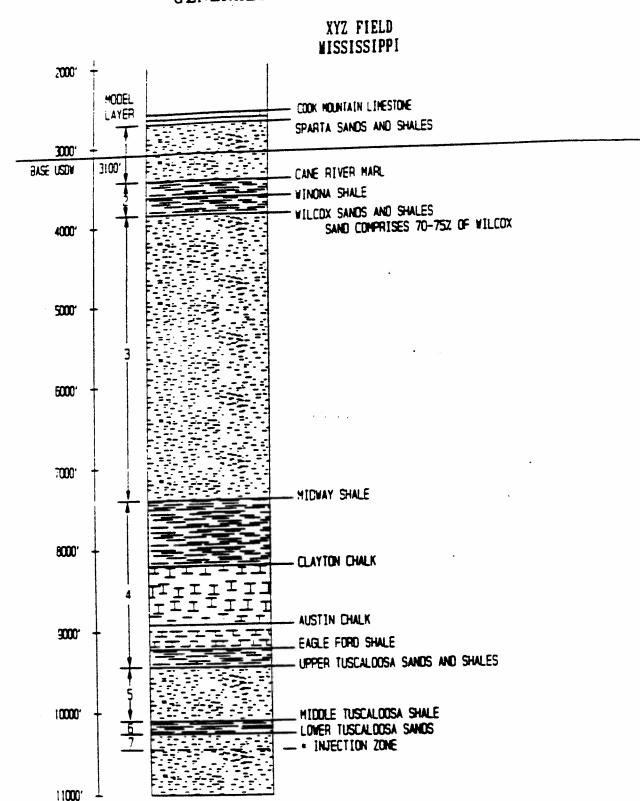
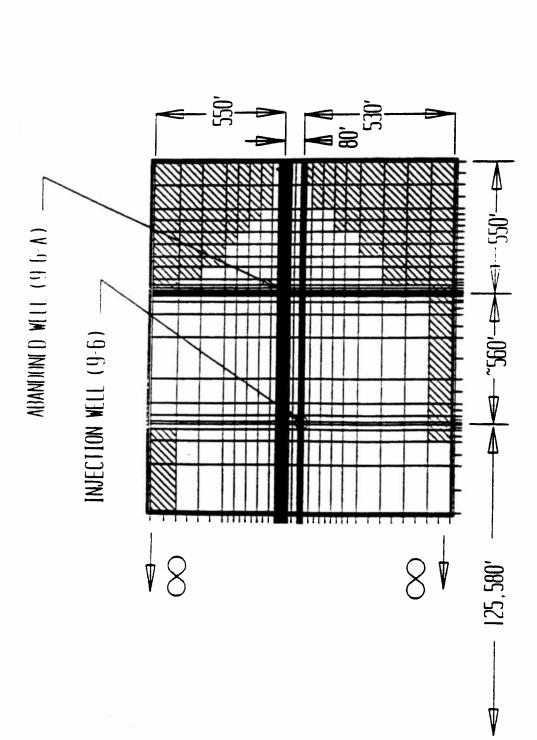


FIGURE 3

FIGURE 4

GENERALIZED STRATIGRAPHIC COLUMN

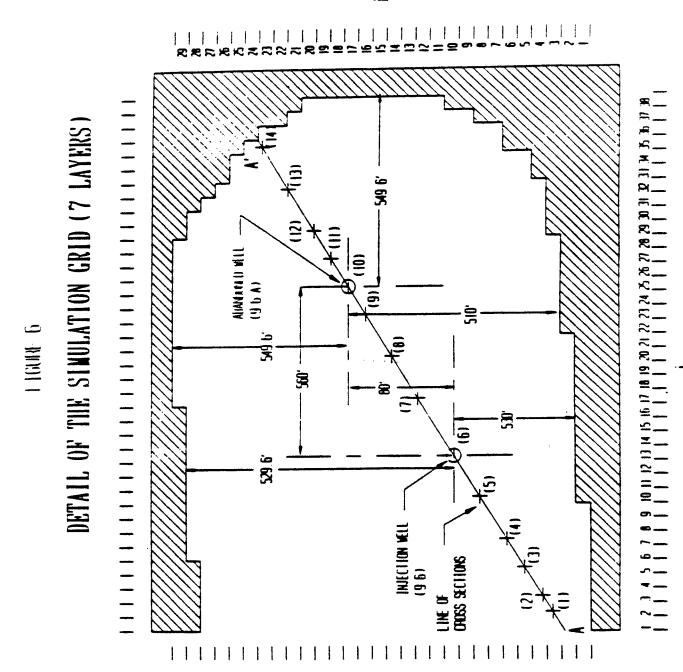




SCALED SIMULATION GRID

FIGURE C

NO-FLOW BLOCK



THE THE PERSON AND THE PERSON OF THE PERSON PERSONS IN

85

The energy company that operates the oilfield under study provided the geologic and engineering parameters and operating schedule for Well 9-6, needed as input to the numerical model. It was assumed that the injection well would operate at near its maximum injection capacity, the constraint being the local fracture gradient of about 0.7 psi per foot of depth. The permeability of the Lower Tuscaloosa Sand was assumed to be a maximum probable 30 millidarcys and a minimum probable 2 millidarcys. The large range is the millidarcys and a minimum probable 2 millidarcys. The large range is the result of uncertainty concerning the effect of residual oil on the permeability to water. A total of about 20 simulation runs were made to calibrate the model and 10 final simulations were run to test various borehole and reservoir conditions. The results of representative simulations are discussed below.

Figure 7 displays the results of a simulation in which the borehole of Well 9-6A was considered to be unplugged. The Lower Tuscaloosa Sand was considered to have a permeability of 30 millidarcys and the injection rate in Well 9-6 considered to be 200 bbl/day. Reservoir pressure at the wellbore of Well 9-6 increased 908 psi over the 10-year simulation period and increased about 752 psi in the Lower Tuscaloosa Sand at the borehole of abandoned Well 9-6A. This pressure increase was transmitted through the Middle Tuscaloosa and through the borehole of Hell 9-6A to the extent that up to a 7.2 psi pressure increase occurred in the Upper Tuscaloosa. Transmission of pressure through Well 9-6A also caused a buildup of up to 4.8 psi in Model Layer 4 but no pressure increase could be observed in the Wilcox Formation or units above the Wilcox. This result indicates that upward flow through abandoned Well 9-6A was insufficient to cause an observable pressure increase in the Wilcox and that no transmission of water to units above the Wilcox would be expected to occur. All subsequent simulations in which the permeability of the Lower Tuscaloosa Sand and the injection rate of Well 9-6 were proportionately varied, yielded the same result.

Cases were also studied where a plug composed of precipitated drilling mud solids was hypothesized to have developed. Figure 8 displays the results of one such simulation in which a plug of only 10-feet in length was considered to have developed in the interval of the Middle Tuscaloosa Formation. The 10-foot plug was assigned a permeability of 10⁻³ millidarcys. As shown in Figure 8, no observable pressure increase developed in layers above the Middle Tuscaloosa.

^{1.} As has been discussed, it is believed that all rotary drilled boreholes will have some hydraulic resistance to flow. In this study, permeabilities of from about 40 to 4000 darcys were assigned to the borehole of Well 9-6A with no observable difference in the results.

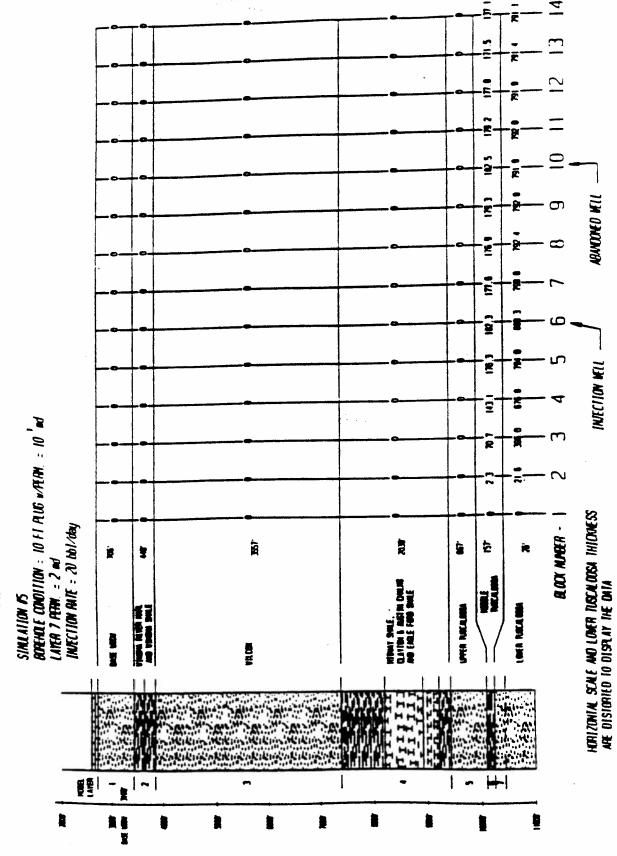
INCREASE IN PRESSURE CPSI) ABOVE HYDROSTATIC ALONG SECTION A-A' AFTER 10 YEARS OF INJECTION HAMINU WIII INVICTION MILL I HERRY BOREHOLE CONDITION : ONEM: MAD FILLED Laner 7 febr = 30 ad HPRIZININ SCALL AND LONGR TUSCALODSA THICKNESS INVECTION PAIR = 200 bbl/day 2 3 ż 2 3 BOOK NUMER . SIMLATION 11 PPER PARKA MEDI I DAEN TURKA DIREN 8) | Ē e e

7

87

FIGURE 8

INCREASE IN PRESSURE (PSI) ABOVE HYDROSTATIC ALONG SECTION A-A' AFTER 10 YEARS OF INJECTION



The conclusion of the example discussed here is that modeling indicates that abandoned Well 9-6A poses no threat to underground sources of drinking water even if the nearby Well 9-6 were to be used for water injection at rate of up to 200 bbl/day over a period of 10 years. It can be expected that similar studies in other geologic and hydrologic situations would show that, in many cases, abandoned wells probably pose no potential for contamination o an USDW under any reasonable set of assumed circumstances. Thus, a differentiation among abandoned wells is needed to identify those locations i which such wells require the close attention of industry and regulatory agencies and those locations where the contamination potential is low to, perhaps, nonexistent.

VI. REFERENCES

Aller, Linda, 1984, Methods for Determining the Location of Abandoned Wells, U.S. EPA-600/Z-83-123, 130 p.

Reeves, M., Johns, N. D., and Cranwell, R. M., 1986b, Data Input Guide for SWIFT II, The Sandia Waste-Isolation Flow and Transport Model for Fractured Media, NUREG/CR-3162 and SAND83-0242, Sandia National Laboratories, Albuquerque, New Mexico.

Ward, D. C., 1987, Modifications to Reeves, et al, 1986, Geotrans, Inc., Herndon, VA.

WARNER, D.L. AND SYED, T., 1986 CONFINING LAYER STUDY-SUPPLIMENTAL REPORT: PREPARED FOR U.S. EPA REGION V CHICAGO ILLINOIS



Confining Layer Study Supplemental Report
Prepared for
U.S. Environmental Protection Agency
Region V, Chicago, Illinois

SUBMITTED BY:



WATER RESOURCES SPECIALISTS
UNDER CONTRACT NO. 68-01-7011

CONFINING LAYER STUDY - SUPPLEMENTAL REPORT

PREPARED FOR U.S. EPA REGION V UNDER CONTRACT NO. 68-01-7011

RESPECTFULLY SUBMITTED

DON L. WARNER, INC.

ROLLA, MISSOURI

ENGINEERING ENTERPRISES, INC.

NORMAN, OKLAHOMA

AUGUST, 1986

DISCLAIMER

Although the information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract No. 68-01-7011 to Engineering Enterprises, Inc., it does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

TABLE OF CONTENTS

CHAP	TER			PAGE
1.	INTR	ODUCTION	• • • • • • • • • • • • • • • • • • • •	1
	1.1	Statement	of the Problem	1
	2.1	Scope and	Nature of Study	3
2.	CONC	LUSIONS		4
3.	RECO	MENDATION	is	8
4.			TERIA FOR CONFINING LAYER	9
	4.1	Injection	and Confining Intervals	9
	4.2	Rock Type	·S	10
	4.3	Stratigra	phy	12
·	4.4	Structura	l Geology	14
		4.4.1	Faults Earth Stresses	15 17
	Refer	ences		22
5.			ITERIA RELATING TO THE CONTINUITY AYERS	23
	5.1	General W	ater Chemistry	23
		5.1.1	Calcium and Magnesium	27
		5.1.2	Sodium	27
		5.1.3	Bicarbonate	28
		5.1.4	Sulfate	28
		5.1.5	Chloride	28
		5.1.6	Silica	29
		5.1.7	Oxygen	29
		5.1.8	Bromide	30
		5.1.9	Nitrate	31

T	a	b	1	e	οĒ	Co	n	t	9	n	t	3
2	a	q	e	2								

		5.1.10	Boron	31
		5.1.11	Uranium	
	5.	2 Anthrop	ogenic Compounds	
	5.		Isotopes	
	5.		Radionuclides	
		5.4.1	Accumulation of Products of Disintegration	36 38
		5.4.2	Uranium Disequilibrium	39
•		5.4.3	Atmospheric Radionuclides	40
	5.5	Conclusi	ions	43
	Ref	erences	•••••••	44
6.	ENG	INEERING P	PROPERTIES OF ROCKS	45
	6.1	Permeabi	lity	45
	6.2	Porosity	•••••••••••	51
	6.3	Compress	ibility	52
		6.3.1	Compressibility of Porous Rock	52
		6.3.2	Compressibility of Formation Waters	53
		6.3.3	Compressibility of Water-Filled Reservoirs	53
	6.4	Basic Roc	k Mechanics	54
		6.4.1	Stress-Strain Relations	54
		6.4.2	Young's Modulus	55
		5.4.3	Poisson's Ratio	57
,	Refe	rences	•••••••••••	64
7.	HYDR.	AULIC FRAC	TURING AND CONFINING	65
	7.1		Fracturing	65

Table of Contents Page 3

	7.	2 Mechanio	s of Fracturing	68
		7.2.1	Fracture Initiation	68
		7.2.2	Fracture Propagation	69
	7.3	Fracture	Pressure Gradients	70
		7.3.1	During Hydraulic Fracturing for Reservoir Stimulation	71
		7.3.2	Low Yolume Hydraulic Fracturing	73
		7.3.3	Step-Rate Injection Method	73
		7.3.4	Step-Rate Injection/Flowback Testing	75
	7.4		Containment in Layered	75
	7.5	Minimum 1	Thickness of Confining Layer	79
	7.6	Additiona Hydraulio	al Important Concepts in Fracturing	82
	Refe	erences		84
3.	CONF	INING LAYE	R EVALUATION PROCEDURES	86
	8.1	Cuttings	and Core Samples	86
	8.2	Water Sam	ples	90
	8.3	Logs	•••••	94
		8.3.1	Sample Logs	96
		8.3.2	Driller's Logs	96
		8.3.3	Drilling Time Logs	97
		8.3.4	Geophysical Logs	99
		8.3.5	Miscellaneous Logs	101
	8.4	Injection	or Pump Testing	103
		8.4.1	Slug or Pulse Testing	110

Table of Contents Page 4

	8.5		Pressure Gradient Estimation mination	111
		8.5.1	Fracture Pressure Gradient Estimation	
		8.5	Fracture Pressure Gradient Determination	
	Refe	erences		. 115
9.			ONFINING LAYERS	
	9.1		ntergranular Flow	
	9.2		Fractured Strata	
	9.3		h Solution Porosity	
	9.4		ly Fractured Strata	
	9.5	Abandoned	Unplugged or Poorly Plugged	
		MGT12	• • • • • • • • • • • • • • • • • • • •	
	Refe	ences		128
10.	IMPRO	PERLY PLUG	GED AND ABANDONED WELLS	129
	10.1	Adequacy of of Injection	f Mud Plugs in Isolation on Zone Fluids	134
	10.2	Methods of	Locating Abandoned Wells	139
	10.3	Plugging of	Wells	140
	Refer	ences	••••••••	148
11.	STATE	POLICIES O	CONCERNING CONFINING LAYERS	149
			••••••	
		DIX I - INF	ORMATION FOR INJECTION WELL SITE	
,	APPENT	DIX II - SO	URCES OF DATA FOR INJECTION LL SITE EVALUATION	
	· On RE	GIONAL AND	ROCEDURES AND CRITERIA LOCAL EVALUATION OF INJECTION ING LAYERS	165





LIST OF FIGURES

	GURE 1BER	PAGE
4-1	Schematic Presentation of a Fault and Joint	16
4-2	Variation of Principal Stresses with Depth in the Continental United States	13
6-1	Stress-Strain Relationship for Linear Elastic Materials	56
6-2	Measurement of Poisson's Ratio	58
7-1	Schematic Diagram of Pressure Change During Hydraulic Fracturing Test	72
7-2	Pressure	74
7-3	Post-Frac Pressure Decline to Determine Closure Stress	76
8-1	Location of Ancona-Garfield Storage Field, Illinois	91
8-2	Composite Columnar Section at Garfield	92
8-3	Typical Mechanical Drilling Log Record	100
8-4	Gamma Ray - Laterolog on Scheuer No. 1 Well at Garfield	102
8-5	Results of Pumping Test with Leaky Aquifer	105
8-6	Cross Section Showing Wells for Garfield Pump Test	107
8-7	Water Levels on Mt. Simon Wells During Garfield Pump Tests	108
8-8	Water Levels on St. Peter and Galesville Zones During Garfield Pump Test	109
8-9	Variation of Overburden Gradient with Depth	113
9-1	Stratigraphic and Hydrogeologic Section, St.	121

Table of Contents
Page 5

9-2	Vertical Upward Velocities of Pore Water in the Confining Layer Between Injection Zones A and B at St. Petersburg, Florida, as Calculated by Computer Model	124
9-3	Concentration Fraction C/Co of Dissolved Chemicals in Zone A as Forced Upward from the Semi-Confining Layer into Zone A by Injection into Zone B at St. Petersburg, Florida	125
10-1	Potential Fluid Migration from an Injection Zone through an Abandoned Well and into a Fresh Water Zone	131
10-2	Hazards of Subsurface Disposal in Areas of Unplugged Wells	133
10-3	Monterey Sand Injection Well, Cat Canyon Field, California	135
10-4	Schematic of Typical Plugs Required by Host States.	145
10-5	United States EPA Plugging Record Form	147
	LIST OF TABLES	
TAB: NUMB:		PAGE
5-1	Major Dissolved Constituents in Groundwater	26
5-2	Dissolved Constituents Which Could Suggest Cross-Formational Movement of Groundwater	33
5-3	Stable Isotopes of Various Elements Potentially Useful in Assessing Hydrogeologic Confinement	35
5-4	Radionuclides of Atmospheric Origin Useful for Studying the Residence Time of Groundwater	41
6-1	Conversion Table for Hydraulic Conductivity Units	48
6-2	Young's Modulus and Poisson's Ratio Values for Various Rock Types	60
8-1	Example of Descriptions of Drilling Cuttings	

Table of Contents Page 7

8-2	Whole Core Analysis on Eau Claire Confining Interval Garfield Gas Storage Area, Illinois	89
8-3	Analyses for Nater Samples Obtained from the Mt. Simon, Galesville and St. Peter Aquifers at the Garfield Gas Storage Area, Illinois	95
3-4	Portion of the Construction History of the Reichold Chemicals Incorporated Well, Alabama	98
9-1	Distance of Vertical Travel of Injected Watewater in Feet/Year Through a 100-Foot-Thick Confining Stratum with Various Permeabilities and Pressure Gradients	119
9-2	Comparison of Pressure Buildups at Observation Well Locations at St. Petersburg, Florida as Calculated by Hickey (1984) and as Calculated for this Study Using SWIP	122
10-1	Summary of Application, Advantages and Disadvantages of each Method which may be used to Locate Abandoned Wells	141

ACKNOWLEDGEMENTS

The Confining Layer Study - Supplemental Report was prepared for the United States Environmental Protection Agency - Region 7 (Chicago, Illinois) under Contract No. 58-01-7011, Work Assignment No. 5-4. Significant additions have been made to an earlier Confining Layer Study prepared for the U.S. EPA - Region V in December, 1984.

Principal Authors

Dr. Don L. Warner

· University of Missouri, Rolla

Mr. Talib Syed

Engineering Enterprises, Inc.

Contributing Author:

Dr. Stanley N. Davis

(Chapter 5)

University of Arizona, Tucson

ESI Project Manager:

Dr. Richard N. Tinlin

Engineering Enterprises, Inc.

EPA Project Officer:

Mr. A. Roger Anzollin

U.S. EPA, UIC Branch

Washington, D.C.

EPA Work Assignment <u>Manager</u>

Mr. Gary D. Harmon

U.S. EPA - Region V Chicago, Illinois

Mr. Gregory Parker and the UIC staff of EPA Region V are thanked for their cooperation and Dr. Stan Davis for his review of the manuscript and editorial comments. Individuals who contributed to the earlier study with their review and comments include Mr. Stu Niemann, Mr. Mark Vendl, and Dr. Kris Kamath of EPA Region V, Mr. Paul Osborne and Mr. Gus Stolz of EPA Region VIII, and Mr. Gene Coker of EPA Region IV. Finally, special



thanks are due to the excellent work done by Mrs. Cindy Jondahl, Ms. Teri Arnold, Mrs. Sharon Moore and Ms. Nancy Simpson of EEI in preparing this manuscript.

CHAPTER 9

PLOW THROUGH CONFINING LAYERS

The entire purpose of the evaluation of a confining layer or layers for containment of injected wastewater is to provide assurance against vertical migration of wastewater or saline water from the injection unit into overlying fresh water bearing aquifers. Such vertical movement could occur as a result of:

- 1. Intergranular flow through unbreached confining strata,
- Flow through naturally fractured or faulted confining strata,
- Flow through confining strata with solution porosity and permeability,
- 4. Flow through artificially fractured confining strata,
- 5. Flow through abandoned unplugged or improperly plugged wells.

Flow under each of these conditions is discussed below.

9.1 Matural Intergranular Flow

If the confining layer is a clastic sedimentary rock, that is, it is composed of discrete sedimentary particles and is unfractured, then fluid flow will be through intergranular spaces. Shales and siltstones and gradations between them are examples of such rocks. Flow through the intercrystalline spaces in chemically deposited rocks such as limestones is also intergranular flow.

Darcy's law for the flow of water through a granular rock is:

$$\mathbf{v} = \frac{\overline{\mathbf{x}} \Delta \mathbf{p}}{\mu \Delta \mathbf{L}} \tag{9-1}$$

where:

v = darcy velocity [cm/sec]

K = permeability [darcys]

u = viscosity [centipoise]

ΔP = pressure differential across the flow distance [atmosphere]

ΔL = flow distance [centimeters]

Furthermore, the actual average intergranular liquid velocity is:

$$\overline{\mathbf{v}} = \underline{\mathbf{v}} \tag{9-2}$$

where:

v = average intergranular velocity [cm/sec]

\$\phi_a = \text{effective porosity}

The fluid pressure in a reservoir into which liquid is being injected is greatest at the injection well face and declines approximately logarithmically away from the borehole. The pressure will also vary with time, increasing as injection continues or declining if injection ceases or the rate is reduced. For purposes of illustration, however, a maximum constant pressure can be assumed to exist at the injection well in order to calculate the rate at which wastewater might be moving vertically through a confining layer. While Equation 9-1 is strictly correct only for horizontal flow, it can be used here for purposes of illustration, if ΔP is considered to be a pressure difference

tial across the confining layer that was induced by fluid injection and where no cross-formational flow potential existed prior to injection. Using Equations 9-1 and 9-2, the values in Table 9-1 were, then calculated. Table 9-1 shows illustrative rates of movement expressed in feet/year, for a range of pressures and permeabilities. For these cases, the confining layer was assumed to be 100 feet thick, the effective porosity to be 10 percent and the viscosity one centipoise.

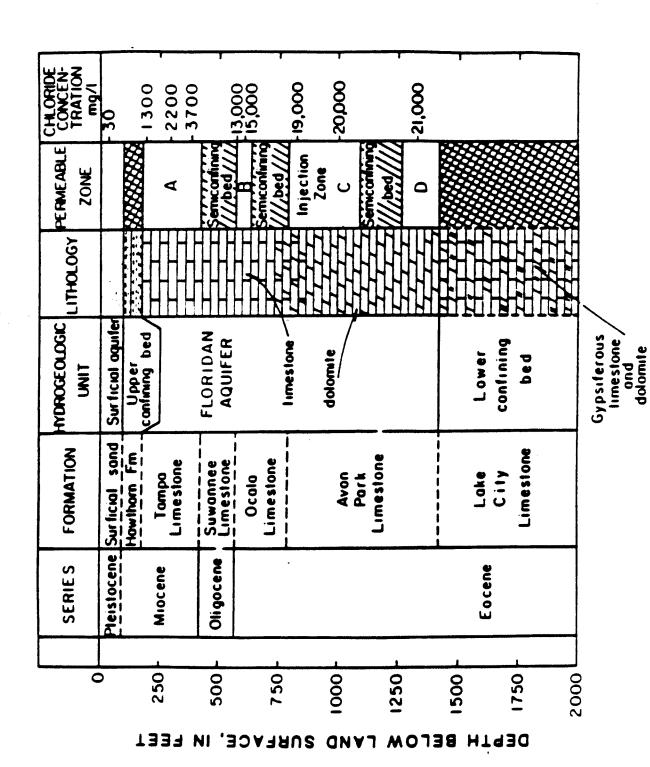
TABLE 9-1 Distance of vertical travel of injected wastewater in feet/year through a 100-foot-thick confining stratum with various permeabilities and injection-induced pressure gradients. The effective porosity was assumed to be 10 percent and the viscosity to be one centipoise.

		P (ps1)		
K (darcys)	500	1,000	2,000	5,000
1 x 10 ⁻³	114 ft/yr	228 ft/yr	456 ft/yr	570 ft/yr
1 x 10 ⁻⁵	1.14	2.28	4.56	5.7
1 x 10 ⁻⁷	1.14×10^{-2}	2.28×10^{-2}	4.56 x 10 ⁻²	5.7×10^{-2}
1×10^{-9}	1.14×10^{-4}	2.28 x 10 -4	4.56 x 10 ⁻⁴	5.7×10^{-4}

A vertical wastewater travel of 114 feet/year would probably be unacceptably high but the assumed permeability in this case $(1 \times 10^{-3} \text{ darcys})$ is at the upper end of values that one might encounter in a confining stratum, whereas a value of 1×10^{-9} darcys is at the other extreme. The travel rates shown in Table 9-1 are only meant to be illustrative and not comprehensive. Additional computations can be made, quite simply, if so desired.

No mention has, so far, been made of the chemical quality of water that might be forced to flow from the injection unit to an overlying aquifer by injection pressure buildup. If the vertical flow is within the radius of spread of wastewater in the injection unit, then the water that would initially enter the overlying aquifer would be from the confining stratum and that would eventually be followed by injected wastewater. Outside of the radius of spread of the wastewater, the water initially entering the overlying aquifer would be from the confining stratum eventually to be followed by natural water from the injection unit.

An example of the type of analysis described above was documented by Hickey (1984) for an injection well facility at St. Petersburg, Florida. The stratigraphic and hydrogeologic section for the St. Petersburg injection site is given in Figure 9-1. Injection was carried out during a period of 32 months beginning in September, 1979, to determine the impact of long-term injection. During the first year of the test, the mean injection rate was 2,750 gpm through a single well into injection zone C and by a postulated wellbore interconnection into injection zone B. Hickey (1984) calculated the vertical velocities in the semiconfining bed between injection zones A and B and also the pressures at various monitor well locations using analytical equations similar to those given here.



Stratigraphic and hydrogeologic section, St. Petersburg injection site (Hickey, 1984). Figure 9-1

A much more powerful and revealing method of analysis, for a problem as complex as that at St. Petersburg, is the use of a numerical model such as the U.S. Geological Survey Saline Water Injection Program or SWIP (INTERCOMP Resource Development and Engineering, Inc., 1976). The SWIP model was used to obtain predicted pressures, vertical velocities and saline water displacements in the injection zones and semiconfining units at St. Petersburg for comparison with Hickey's (1984) results. Table 9-2 shows a comparison of pressures at selected monitoring points at the St. Petersburg injection well site as calculated by Hickey (1984) using analytical equations and as calculated for this study by use of the SWIP model. No field data were given by Hickey to allow comparison between observed and calculated pressures.

TABLE 9-2 Comparison of pressure buildups at observation well locations at St. Petersburg, Plorida as calculated by Hickey (1984) and as calculated for this study using SWIP.

Pressure	Buildun
reserve	Battann

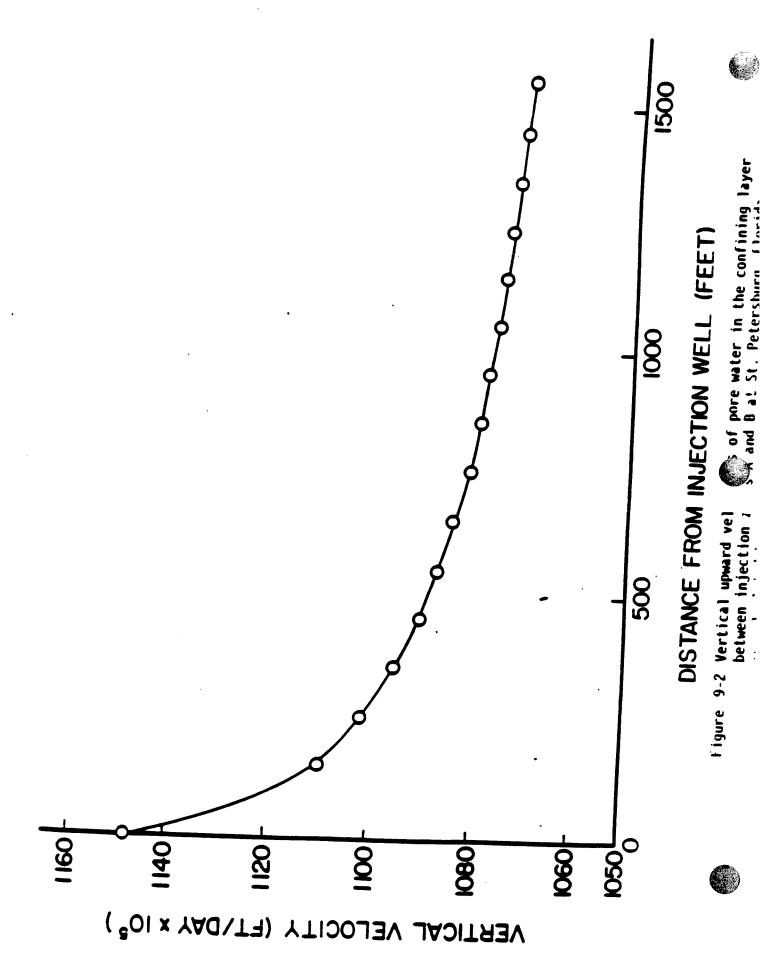
Observation Well	Distance from Injection Well	Prom Bickey	Prom SWIP
A3	0	4	2.9
B6	45	1.6	2.5
B7	66	2.4	2
B8	100	0.5	1.0
B9	115	0.1	.08
Bl	660	0.1	1.0
B2	660	0.1	1.0
B3	660	i	1.2
B4	660	1.4	1.3
B 5	660	0.5	
C2	1300	0.8	.8
C3	1390	0.3	1.8

Figure 9-2 shows upward vertical velocities of pore water in the confining layer between injection zones B and A. The velocities are those computed by the SWIP model to exist after one year of injection at 2,750 gpm into zones B and C as explained above. For comparison, Hickey (1984) calculated velocities, using analytical equations, of 0.005 to 0.05 ft/day at a distance of about 733 ft. from the injection well and 0.01 to 0.1 ft/day immediately adjacent to the injection well. Figure 9-3 shows the calculated concentration fraction (C/C_O) of dissolved chemicals in zone A as forced upward from the semiconfining layer into zone A from injection into zone B. For example, if the semiconfining layer were to contain water with a chloride concentration of 13,000 mg/l (Figure 9-1), then the chloride concentration in the lower 20 feet of zone A would be increased by about:

(13,000 mg/l) (0.056) = 728 mg/l immediately adjacent to the injection well after one year of injection.

9.2 Naturally Fractured Strata

The effect of naturally occurring fractures in a confining layer is, commonly, to greatly increase the permeability and to create a secondary form of porosity which is small in magnitude but effectively interconnected. The net result is that wastewater transport through a fractured caprock may be tens or hundreds of times more rapid than through the same rock in the unfractured state.



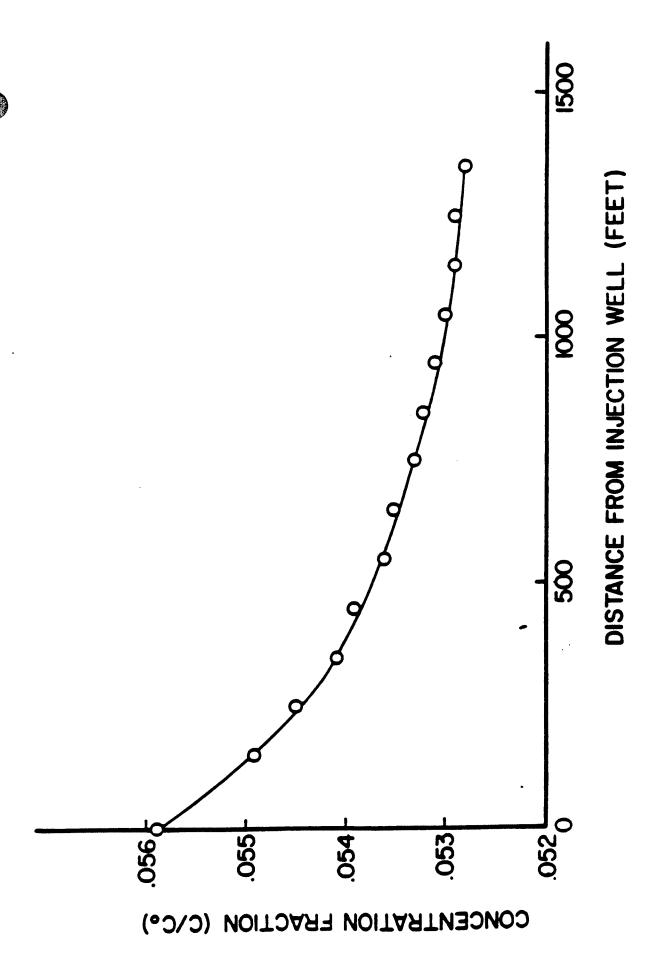


Figure 9-3 Concentration fraction C/C₀ of dissolved chemicals in zone A as forced upward from the semiconfining layer into zone A by injection into zone B at St. Petersburg, Florida

The analysis of flow through fractured rock is often treated no differently than flow through granular media. This approach is probably acceptable in many cases; but, where fractures are widely spaced, are of wide aperture or have a particular directional trend other mathematical methods may be needed (Freeze and Cherry, 1979, p. 73-74).

9.3 Strata With Solution Porosity

Solution porosity is often developed in conjunction with fractures and in soluble rocks and the above statements concerning fracture porosity will, thus, commonly be true where solution porosity exists.

9.4 Artificially Fractured Strata

Artificial fractures differ from naturally occurring ones in that they are more likely to be represented by a single vertical or horizontal fracture as opposed to a network of fractures. Also, if the artificial fracture has been deliberately induced, it will be propped open with sand, glass beads or other propping agents. Equations have been developed to predict fluid pressure distribution patterns in the vicinity of a well injection into single vertical or a horizontal fracture (Gringarten and others, 1974; Gringarten and Ramey, 1974). However, it is not likely that such equations would find application to the flow of fluid through a confining layer, since injection would be precluded if it were known that the confining layer was breached by an induced fracture.

9.5 Abandoned Unplugged or Poorly Plugged Wells

An abandoned, unplugged or poorly plugged well, penetrating the injection unit, within the radius of pressure influence of the injection well can act as a point leak from the injection unit to overlying aquifers. This is, of course, the main basis for the area of review determination required in the UIC regulations promulgated under the Safe Drinking Water Act.

while development of analytic equations to predict rates of interaquifer flow through a wellbore should not be particularly difficult, this has apparently not been done. However, work is currently in progress toward the formulation of analytic equations for this purpose in the Earth Sciences Division of the Lawrence Berkeley Laboratory, Berkeley, California (written communication P.A. Witherspoon, 1986).

REFERENCES

CHAPTER 9

- Freeze, R. A. and Cherry, J. A. <u>Groundwater</u>. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 1979. 553 pp.
- Gringarten, A. C. and H. J. Ramey. 1974. "Unsteady-State Pressure Distributions Created by a Well With a Single Horizontal Fracture." <u>Journal of SPE</u>, August, 1974. pp. 347-360.
- Gringarten, A.C., H.J. Ramey, and R. Raghaven. 1974. Unsteady-State Pressure Distributions Created by a Well With a Single Infinite-Conductivity Vertical Fracture. <u>Journal of SPE</u>. August. pp. 347-360.
- Hickey, J. J. "Subsurface Injection of Treated Sewage into a Saline Water Aquifer at St. Petersburg, Florida." Groundwater. Vol. 22, No. 1, 1984. pp. 48-55.
- Warner, D. L. et al. "Radius of Pressure Influence of Injection Wells." U.S. Environmental Protection Agency, EPA-600/2-79-170, 1979. 204 pp.



WESSELMAN, J.B AND ARONOW, S., 1971 GROUNDWATER RESOURCES OF CHMABERS AND JEFFERSONCOUNTIES, TEXAS

TEXAS WATER DEVELOPMENT BOARD



Report 133

DIV	KION	FHF	COPY
ואוע	101017	Liti	CU:

DO NOT REMOVE FROM REPORTS DIVISION FILES.

printing
Completed on: Aug 30
No. Copies 847
Initial: 39.K

GROUND-WATER RESOURCES OF CHAMBERS AND JEFFERSON COUNTIES, TEXAS

AUGUST 1971



CORRECTIONS FOR REPORT 133

Correct size of reduction page numbers on Tables 4 and 7 and 1. $\,$

With a section on Quaternary Geology

Ву

Saul Aronow Department of Geology Lamar State College of Technology

Prepared by the U.S. Geological Survey in cooperation with the Texas Water Development Board

August 1971

TEXAS WATER DEVELOPMENT BOARD

W. E. Tinsley, Chairman Robert B. Gilmore Milton T. Potts

Marvin Shurbet, Vice Chairman John H. McCoy Carl Illig

Harry P. Burleigh, Executive Director

Authorization for use or reproduction of any material contained in this publication, i.e., not obtained from other sources, is freely granted without the necessity of securing permission therefor. The Board would appreciate acknowledgement of the source of original material so utilized.

Published and distributed by the Texas Water Development Board Post Office Box 13087 Austin, Texas 78711

TABLE OF CONTENTS

ge
1
3
3
3
3
4
4
4
6
6
6
6
7
7
7
7
1
1
1
2
3
8
8
8
8
5

TABLE OF CONTENTS (Cont'd.)

	Pag
RELATION OF WATER-LEVEL DECLINES TO LAND-SURFACE SUBSIDENCE	25
WELL CONSTRUCTION	27
QUALITY OF GROUND WATER	28
Suitability for Public Supply	28
Suitability for Industrial Use	28
Suitability for Irrigation	30
RELATIONSHIP OF FRESH GROUND WATER TO SALINE GROUND WATER	30
DISPOSAL OF OIL-FIELD BRINES AND OTHER CONTAMINANTS	32
PROTECTION OF WATER QUALITY IN OIL-FIELD DRILLING OPERATIONS	33
AVAILABILITY OF GROUND WATER	33
Evangeline Aquifer	33
Chicot Aquifer	34
Lower Unit	
Upper Unit	34
QUATERNARY GEOLOGY, by Saul Aronow	34
	34
General Stratigraphy and Structure	43
Beaumont Clay	43
Deltaic and Meander Belt Deposits	43
Barrier Island and Beach Deposits	44
Mounds and Depressions	44
Geologic Age	51
Deweyville Deposits of Bernard (1950)	51
Holocene Deposits	51
Alluvial and Deltaic Deposits	51
Coastal Marsh, Mudflat, and Beach (Chenier) Deposits	53
Geologic History	53
CONCLUSIONS AND RECOMMENDATIONS	54
REFERENCES CITED	55

TABLE OF CONTENTS (Cont'd.)

	TABLES	
1.	Geologic and Hydrologic Units Used in This Report and in Recent Reports in Nearby Areas	8
2.	Summary of Aquifer Tests	16
3.	Source and Significance of Dissolved-Mineral Constituents and Properties of Water	29
4.	Records of Wells in Chambers and Jefferson Counties and Adjacent Areas	58
5.	Drillers' Logs of Wells in Chambers and Jefferson Counties	107
6.	Water Levels in Wells in Chambers and Jefferson Counties	138
7.	Chemical Analyses of Water From Wells in Chambers and Jefferson Counties	145
	FIGURES	
1.	Map Showing Location of Chambers and Jefferson Counties	3
2.	Graphs Showing Average Annual Precipitation, Average Monthly Temperature, and Average Monthly Precipitation at Beaumont	5
3.	Map Showing Approximate Altitude of the Base of the Chicot Aquifer and Locations of Salt Domes	9
4.	Idealized Block Diagram Illustrating Ground-Water Circulation Around Salt Domes	12
5.	Graph Showing Relation of Drawdown to Transmissibility and Distance	14
6.	Graph Showing Relation of Drawdown to Distance and Time as a Result of Pumping Under Artesian Conditions	15
7.	Graph Showing Relation of Drawdown to Distance and Time as a Result of Pumping Under Water-Table Conditions	15
8.	Hydrographs Showing Changes in Water Levels in Wells Tapping Various Aquifers in Chambers County	19
9.	Hydrographs Showing Changes in Water Levels in Wells Tapping the Upper and Lower Units of the Chicot Aquifer in Jefferson County	20
10.	Map Showing Approximate Altitudes of Water Levels in Wells Screened in the Lower Unit of the Chicot Aquifer, 1941 and 1966	21
11.	Map Showing Approximate Altitudes of Water Levels in Wells Screened in the Upper Unit of the Chicot Aquifer, 1941 and 1966	23
12.	Map Showing Subsidence of the Land Surface in the Houston District, 1943-64	26
13.	Diagram Showing Construction of Industrial and Public Supply Wells	27
14.	Diagram for the Classification of Irrigation Waters	31
15.	Graphs Showing Comparison Between Surface-Casing Requirements in Oil Fields and Depth of Base of Sands Containing Fresh to Slightly Saline Water	33

TABLE OF CONTENTS (Cont'd.)

		Pag
16.	Map Showing Approximate Altitude of the Base of Slightly Saline Water	35
17.	Map Showing Approximate Altitude of the Base of Fresh Water and Thickness of Sand Containing Fresh Water in the Evangeline Aquifer	37
18.	Map Showing Approximate Altitude of the Base of Fresh Water and Thickness of Sand Containing Fresh Water in the Lower Unit of the Chicot Aquifer	39
19.	Map Showing Approximate Altitude of the Base of Fresh Water in the Upper Unit of the Chicot Aquifer	41
20.	Geologic Map of Chambers and Jefferson Counties	45
21.	Map Showing Selected Features From the 1965 Soil-Survey Map of Jefferson County	47
22.	Map Showing Meander-System and Delta Development of the Beaumont Clay	49
23.	Map Showing Subsurface Contours on Top of the Oxidized Pleistocene Deposits in the Vicinity of Sabine Lake, Texas and Louisiana (From Kane 1959)	52
24.	Map Showing Location of Wells in Chambers and Jefferson Counties and Adjacent Areas	175
25.	Hydrologic Section A-A', Harris, Chambers, Liberty, Jefferson, Hardin, and Orange Counties	177
26.	Hydrologic Section B-B', Harris, Chambers, and Jefferson Counties	179
27.	Hydrologic Section C-C', Hardin and Jefferson Counties	181
28.	Hydrologic Section E-E' and Hydrologic Diagram D-D' at Barber's Hill Dome, Chambers County	183

GROUND-WATER RESOURCES OF CHAMBERS AND JEFFERSON COUNTIES, TEXAS

ABSTRACT

The hydrologic units of Chambers and Jefferson Counties, the Chicot and Evangeline aquifers and the Burkeville aquiclude, are composed of gravel, sand, silt, and clay of Miocene, Pliocene, Pleistocene, and Holocene age.

Only small quantities of fresh ground water, less than 1,000 mg/l (milligrams per liter) dissolved solids, are available in Chambers and Jefferson Counties, and these supplies are fairly well developed. In 1965, approximately 18.6 mgd (million gallons per day) of ground water was used in the report area. Of this amount 10 mgd was fresh water produced from wells in adjacent Hardin and Orange Counties. Total pumpage of fresh water in Chambers and Jefferson Counties was approximately 6.1 mgd. About 2.5 mgd was slightly or moderately saline water.

Industrial use of ground water was approximately 9 mgd, of which 4 mgd was imported. Municipal use of ground water was approximately 8 mgd, of which 6 mgd was imported from Hardin County by the city of Beaumont. Irrigation use in 1965 was approximately 1.5 mgd. Use of ground water for irrigation will remain small because most of the available water is too saline.

Two aquifers, the Chicot (including the upper and lower units), and the Evangeline, furnish fresh water to wells. Fresh water is produced from wells in the Chicot aquifer in the Mont Belvieu, Houston Point, Anahuac, Galveston Bay, and Trinity Bay areas of Chambers County; in a small strip 2 to 4 miles wide along the eastern and northern boundaries of Jefferson County; and in the Hamshire-Winnie area of Chambers and Jefferson Counties. The Evangeline aquifer produces fresh water in the Mont Belvieu and Houston Point areas of Chambers County. Salinization of water in the aquifers has occurred in the vicinity of shallow salt domes.

Additional small supplies of fresh ground water can be developed in the present producing areas. The largest undeveloped source of fresh water underlies Galveston Bay in Chambers County. Large scale increased usage of ground water will require further

importation from neighboring counties.

Most areas in both counties are underlain by very little or no fresh water, but large quantities of slightly and moderately saline ground water (1,000 - 10,000 mg/l) are present at shallow depths in all areas except in the vicinity of shallow salt domes.

Aquifer tests were made in 22 wells. Coefficients of permeability ranged from 108 to 1,670 gpd (gallons per day) per square foot. The highest permeability (1,670 gpd per square foot) was determined in a brackish-water well completed in the lower unit of the Chicot aquifer. The permeability of the sands of the Evangeline aquifer (244 and 327 gpd per square foot) approximate the permeability measured in the Houston district and in Jasper and Newton Counties.

Water levels have declined generally in both counties. The largest decline is due to pumping in adjacent Harris County. The maximum decline was estimated to be at least 150 feet in the lower unit of the Chicot aquifer in the area adjacent to Baytown in Harris County. This major decline has resulted in a land-surface subsidence of about 2 feet.

The exposed formations in Chambers and Jefferson Counties consist of Pleistocene and Holocene deposits, of which the Beaumont Clay of Pleistocene age is the oldest. Remnants of the relict Ingleside barrier island and beach system are enclosed within the Beaumont. The Deweyville deposits of Bernard (1950), which are topographically lower than the Beaumont, underlie the high terraces that border the Holocene floodplains of the Trinity and Neches Rivers. The Holocene deposits are alluvial and deltaic deposits and comparatively low lying.

The Beaumont Clay, which is the most extensively exposed formation, is a sequence of deltaic and meander-belt deposits of the Pleistocene Trinity River. The Beaumont is probably less than 100 feet thick. On the basis of radiocarbon dating, the formation is probably more than 30,000 years old.

GROUND-WATER RESOURCES OF CHAMBERS AND JEFFERSON COUNTIES, TEXAS

INTRODUCTION

Purpose and Scope of the Investigation

The investigation of ground-water resources in Chambers and Jefferson Counties began in September 1965 as a cooperative project between the U.S. Geological Survey and the Texas Water Development Board. The purpose of the project was to determine the occurrence, availability, dependability, quality, and quantity of ground water suitable for public supply, industrial use, and irrigation.

The general scope of the investigation included the collection, compilation, and analysis of data; determination of the location and extent of the water-bearing formations; determination of the hydrologic characteristics of the water-bearing sands; a study of the chemical quality of the water; and estimates of the quantities of ground water available for development.

One section of the report presents a previously unpublished study of the Quaternary geology of the area.

Location and Extent of the Area

Chambers and Jefferson Counties are situated on the upper Texas Gulf Coast in the West Gulf Coastal Plain physiographic province (Fenneman, 1938). The two counties, which have a combined area of 1,562 square miles, are bounded on the north by Liberty and Hardin Counties; on the east by the Neches River, Sabine Lake, and Orange County; on the south by Galveston Bay and the Gulf of Mexico; and on the west by Galveston Bay, Cedar Bayou, and Harris County. Anahuac, the county seat of Chambers County, is 40 miles east of Houston; Beaumont, the county seat of Jefferson County, is 80 miles east of Houston (Figure 1).



Figure 1.—Location of Chambers and Jefferson Counties

Economic Development

The largest segment of the economy of Chambers and Jefferson Counties is based on the production of petroleum, petrochemicals, natural gas, and sulfur. Since the discovery of oil at Spindletop in 1901, a total of approximately 800 million barrels have been produced in the two counties.

Beaumont and Port Arthur are centers of a petroleum-based industrial complex served by the Intracoastal Waterway and other canals suitable for oceangoing vessels. Timber, cattle, fresh and salt-water fish, and agricultural products are other important elements of the economy.

In 1965, Chambers and Jefferson Counties had estimated populations of 11,100 and 268,000, respectively. Anahuac, the largest town in Chambers County, had a 1965 population of 2,200; Beaumont, the largest city in Jefferson County, had a 1965 population of 127,800.

Climate

Chambers and Jefferson Counties have a warm humid climate. Precipitation, which averages about 54 inches annually, is well distributed throughout the year but is greatest from May to September.

The average annual temperature at Beaumont is about 21°C (70°F). Temperatures below freezing occur on the average of only 12 days per year, and temperatures about 38°C (100°F) are unusual. The approximate dates of the first and last killing frosts are December 2 and March 2. The average annual precipitation, average monthly temperature, and average monthly precipitation at Beaumont for the period of record beginning in 1931 are shown in Figure 2.

Gross lake-surface evaporation averaged about 47 inches annually for the period 1940 to 1965 (Kane, 1967).

Physiography and Drainage

Chambers and Jefferson Counties are on the extreme seaward margin of the West Gulf Coastal Plain physiographic province and entirely within the Grassland Coastal Prairie Region of Texas (Walker and Miears, 1957). The physiography is of three general types: (1) flat to gently rolling upland, which includes most of the area; (2) the valleys of the Trinity and Neches Rivers; and (3) the coastal border. Altitudes range from sea level to a maximum of 81 feet above sea level at Mont Belvieu (Barbers Hill salt dome) in western Chambers County.

Along a line from Smith Point to Beaumont, a series of remnants of abandoned beaches and beach ridges reach altitudes ranging from 15 to 25 feet. The more prominent of these sandy remnants are about 5 feet above the upland surface. Salt domes form two prominent hills on the upland surface: Barbers Hill, in northwestern Chambers County, about 40 feet above the general land surface and Big Hill, in southwestern Jefferson County, about 20 feet high.

The major streams in Chambers County are the Trinity River, which drains the northwestern part of the county and flows into Trinity Bay near Anahuac; Cedar Bayou, which forms the western boundary of the county and flows into Galveston Bay; Double Bayou, which drains the central part of the county and flows into Trinity Bay south of Anahuac; and Oyster Bayou, Onion Bayou, and East Bay Bayou, which drain the eastern part of the county and flow into East Bay.

The major streams in Jefferson County are the Neches River, which drains the eastern part of the county and flows into Sabine Lake; Pine Island Bayou, which forms the northern boundary of the county and flows into the Neches River; Taylor Bayou and its

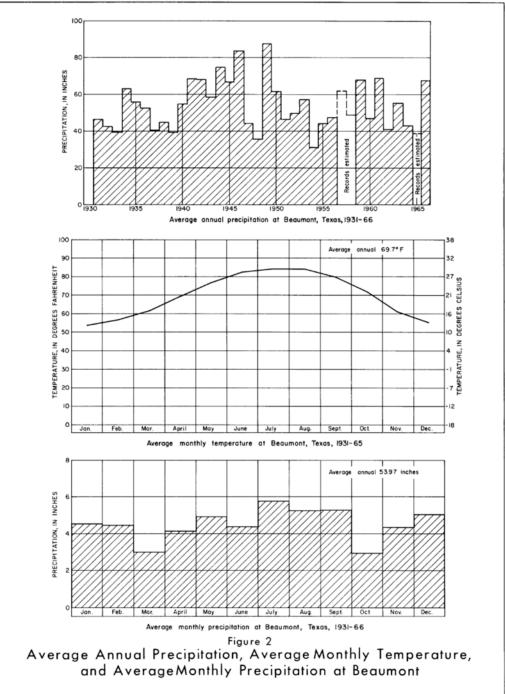
principal tributaries, Hillebrandt and Big Hill Bayous, which drain the western part of the county and flow into Sabine Lake south of Port Arthur; and Spindletop and Salt Bayous, which drain the southern part of the county and flow into the Intracoastal Waterway.

Urbanization and rice cultivation have resulted in the canalization of many streams and the construction of ditches and canals for drainage and irrigation. In some places, natural drainage directions have been changed by deepening parts of the streams.

Methods of Investigation

The following items were included in the investigation of the ground-water resources of Chambers and Jefferson Counties:

- An inventory was made of all industrial, public supply, and irrigation wells, and of a representative number of domestic and livestock wells (Table 4). Locations of the wells are shown on Figure 24.
- 2. Electrical logs and drillers' logs of water wells and oil tests were used for construction of the hydrologic sections (Figures 25 through 28) and for determination of the total thickness of sands containing fresh water (Figures 17 and 18).
- An inventory was made of the withdrawal of ground water for public supply, irrigation, and industrial use.
- Pumping tests were made to determine the hydraulic characteristics of the water-bearing sands (Table 2).
- Altitudes of water wells were determined from topographic maps.
- Measurements of water levels were made in wells, and available records of past fluctuations of water levels were compiled (Table 6 and Figures 8 through 11).
- 7. Climatological records were collected and compiled (Figure 2).
- 8. Analyses of water samples were made to determine the chemical quality of the water (Table 7).
- Maps, sections, and graphs were prepared to correlate and illustrate geologic and hydrologic data.
- The hydrologic data were analyzed to determine the quantity and quality of ground water available for development.
- 11. Data were compiled on the subsidence of the land surface (Figure 12).



From records of U.S. Weather Bureau

12. Problems related to the development and protection of ground-water supplies were studied.

Previous Investigations

Taylor (1907) included wells in Chambers and Jefferson Counties in his report on the underground waters of the Coastal Plain of Texas. Duessen (1914), in a reconnaissance report on the underground waters of the southeastern part of the Texas Coastal Plain, discussed the ground-water geology of Chambers and Jefferson Counties and included a list of wells and springs and drillers' logs of wells.

Livingston and Cromack (1942) inventoried wells in Chambers and Jefferson Counties in 1941 and 1942, and Doyel (1956) published an updated report on Chambers County. Much of the data in these reports was used in this investigation.

Reports by Wood (1956), and Wood, Gabrysch, and Marvin (1963) discussed the ground-water supplies available from the principal water-bearing formations in the Gulf Coast region of Texas, including Chambers and Jefferson Counties.

Water levels have been measured and water samples collected systematically since 1949 in the western part of Chambers County as part of a continuing ground-water program in Harris and Galveston Counties.

Periodic measurements of water levels in wells in Chambers and Jefferson Counties have been made since 1949 as part of the statewide observation-well program in Texas. Records of these measurements are published periodically by the Texas Water Development Board, and records of selected wells in Chambers and Jefferson Counties are published by the U.S. Geological Survey in reports on water levels and artesian pressures in the United States (Hackett, 1962).

Well-Numbering System

The well-numbering system used in this report is the system adopted by the Texas Water Development Board for use throughout the State. Under this system, each 1-degree quadrangle in the State is given a number consisting of two digits. These are the first two digits in the well number. The 1-degree quadrangles are divided into 7½-minute quadrangles which are given two-digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each 7½-minute quadrangle is subdivided into 2½-minute quadrangles and given a single digit number from 1 to 9. This is the fifth digit of the well number. Each well within a 2½-minute quadrangle is given a two-digit number as it is inventoried, starting with 01. These are the last two digits of the well number.

Only the last three digits are shown on the well-location map (Figure 24). The second two digits are generally shown in the northwest corner of each 7½-minute quadrangle, and the first two digits are shown by the large double-lined numbers.

In addition to the 7-digit well number, a two-letter prefix is used to identify the county. Prefixes for Chambers, Jefferson, and adjacent counties are as follows:

COUNTY	PREFIX	COUNTY	PREFIX
Chambers	DH	Hardin	LH
Jefferson	PT	Liberty	SB
Orange	υJ	Harris	LJ

Thus, well DH-64-11-802 (which supplies water for the city of Anahuac) is in Chambers County (DH), in the 1-degree quadrangle 64, in the 7½-minute quadrangle 11, in the 2½-minute quadrangle 8, and was the 2nd well (02) inventoried in that 2½-minute quadrangle.

Acknowledgments

The author acknowledges the assistance of the many county, municipal, and industrial officials who aided in this project. Particular appreciation is expressed to Jett Hankamer and to personnel of Humble Oil and Refining Co., Mobil Oil Corp., Pure Oil Co., Placid Oil Co., Gulf States Utilities Co., Diamond Alkali Co., Warren Petroleum Corp., and Chambers County Water Control and Improvement District No. 1 for permitting and assisting in pumping tests in wells. The Houston Lighting and Power Co. furnished information as it was collected in their testing program east of Baytown.

Well drillers supplied drillers' logs, electrical logs, and well-completion data; and all landowners contacted granted access to their property, wells, and records.

Dr. Saul Aronow, Department of Geology, Lamar State College of Technology, prepared the section of the report on Quaternary geology and aided the author in the task of relating geology to hydrology.

HYDROLOGIC AND GEOLOGIC UNITS

The geologic units composing the aquifers in Chambers and Jefferson Counties are, from oldest to youngest: the Fleming Formation of Miocene age; the Goliad Sand of Pliocene age; the Willis Sand of Pliocene(?) age; the Bentley Formation, Montgomery Formation, and Beaumont Clay of Pleistocene age; the Deweyville deposits of Bernard (1950) of Pleistocene(?) age; and the alluvial, deltaic, coastal marsh, mudflat, and

beach (chenier) deposits of Holocene age. The correlation of geologic and hydrologic units is shown in Table 1.

The Beaumont Clay and the Holocene deposits (described in the section on Quaternary geology) crop out within the two counties. Their surface relationships are shown on the geologic map (Figure 20). The older formations crop out in the counties to the north.

The geologic units are generally composed of sand, silt, and clay, with lesser amounts of gravel, marl, and lignite. Faults are common, especially in the vicinity of salt domes, but surface traces of the fault zones are rarely discernible. Some, but not all, of the salt domes are marked by surface features such as higher altitudes, topographic depressions, or a combination of both.

Figures 25, 26, 27 and 28 are hydrologic sections showing the aquifers, their stratigraphic relationship, and the salinity of the water they contain.

Burkeville Aquiclude

The Burkeville aquiclude, the lowermost hydrologic unit discussed in this report, is principally a clay section within the Fleming Formation and is equivalent, at least in part, to the Castor Creek Member (Fisk, 1940) of the Fleming Formation of Kennedy (1892), as mapped by Rogers and Calandro (1965) in Vernon Parish, Louisiana. The Burkeville is also equivalent to "Zone 2" of Lang, Winslow, and White (1950) in the Houston district.

The Burkeville ranges in thickness from 130 to 300 feet. The unit contains minor amounts of sand in some places but is not a source of water in Chambers and Jefferson Counties. The significance of the Burkeville in the two counties is that it forms the lower confining layer for the overlying Evangeline aquifer.

Evangeline Aquifer

The Evangleine aquifer is the lowermost unit containing fresh or slightly saline water in Chambers and Jefferson Counties. The Evangeline overlies the Burkeville aquiclude and includes the Goliad Sand and sands in the upper part of the Fleming Formation. The aquifer is equivalent to the "heavily pumped" layer of Wood and Gabrysch (1965) in the Houston district. In Louisiana, the unit is equivalent to the Blounts Creek Member (Fisk, 1940) of the Fleming Formation of Kennedy (1892) in Vernon Parish (Rogers and Calandro, 1965) and the Foley Formation in Calcasieu Parish (Harder, 1960).

The Evangeline is about 1,400 feet thick in northern Jefferson County and increases in thickness toward the Gulf. The aquifer yields fresh water to large wells in northwestern Chambers County.

Chicot Aquifer

The Chicot aquifer includes all deposits above the Evangeline aquifer. The unit consists of the Willis Sand, the Bentley Formation, the Montgomery Formation, the Beaumont Clay, the Deweyville Deposits of Bernard (1950), and the Holocene alluvium.

The physical basis for separation of the Evangeline and Chicot is the difference in lithology and permeability. In some areas, the two aquifers are separated by beds of clay, but such beds are not continuous. The units differ in average grain size, cementation, and compaction. The higher permeabilities are usually associated with the Chicot.

The differences noted may be recognized in ways other than by examination of the sediments. A displacement of the spontaneous-potential curve of an electrical log as the logging tool passes out of the Evangeline into the Chicot often marks the contact between the two lithologically dissimilar aquifers. In addition, the formation factor (ratio between aquifer resistivity and aquifer water resistivity) for the two aquifers is generally significantly different. The formation factor for the Chicot aquifer is usually greater. In some areas, where lithologic differences are not pronounced or where changes in water quality makes comparative readings difficult or impossible, the contact between the two aquifers is not readily apparent from electrical logs.

In parts of eastern Jefferson County and western Chambers County, the Chicot aquifer is divided into two units by a clay bed that separates an upper sand section from a lower sand section. There are significant differences in water levels in wells completed in the upper and lower units of the Chicot in eastern Jefferson County and western Chambers County. These sands merge in some places, and in other places, one of the sands may be absent.

In some parts of the two counties, the upper and lower units of the Chicot merge into one large mass of interbedded and interconnected sand and clay as much as 1,600 feet thick. In these areas, determination of a boundary between the two units becomes impossible. This is especially true near some of the shallow piercement-type salt domes and in a large area in central Chambers County. The configuration of the base of the Chicot aquifer and the locations of most of the salt domes in the area are shown on Figure 3.

Lower Unit

In the downdip (southeast) parts of Chambers and Jefferson Counties, the lower unit of the Chicot aquifer is generally two or more massive sands separated by clay. These sands are probably equivalent to the "500-foot" and "700-foot" sands as mapped in Calcasieu Parish, Louisiana (Harder, 1960). In reports on Galveston and Harris Counties, the massive sands of the lower Chicot

		HARDER	(1960)	ROGERS AND		RECENT TEXAS REPORTS	BAKER (1964)	WESSELMAN (1965)	WOOD AND GAB- RYSCH (1965)	1/	THIS	REPORT
SYSTEM	SERIES	FORMATION	HYDROLOGIC UNIT	GROUP OR FORMATION	HYDROLOGIC UNIT	FORMATION	HYDROLOGIC UNIT	HYDROLOGIC UNIT	HYDROLOGIC UNIT	HYDROLOGIC UNIT		LOGIC
	Holocene	Alluvium		Alluvium	Alluvium	Alluvium <u>2</u> /	G _		Beaumont		Upper	Chicot
		Prairie Formation	Chicot shallow	Stream terrace	Stream terrace	Beaumont Clay	L F	Upper aquifer		Chicot aquifer	Chicot	
Quaternary	B1-1	Montgomery Formation	"200 foot"	and upland deposits	and upland deposits	Lissie ery Formation	C O	Middle aquifer	Alta Loma Sand of Rose (1943)			aqu i fer
	Pleistocene	Bentley Formation	"500 foot"			tion Bentley 3/ Formation	S T		Rose (1943)		Lower	
		Willianna Formation	"700 foot"			Willis Sand 4/	Q I				Chicot	
		Foley Formation	Evangeline aquifer	Fleming Formation	Blounts Creek Member	Goliad Sand	I F E	Lower aquifer	Heavily pumped layer	Evangeline aquifer	Evange i aquifer	
Tertiary	Pliocene			of Kennedy (1892)	of Fisk (1940)		R					
		Fleming Formation of Fisk		, , , , , ,	Castor Creek Member of	Fleming Formation 5/						
	Miocene	(1940)			Fisk (1940)				Zone 2	Burkeville aquiclude	Burkevi aquiclu	

1/ Wesselman (1967), Tarver (1968a and 1968b), Anders and others (1968), Sandeen (1968), and Wilson (1967).

2/ Floodplain and terrace deposits in Baker (1964).

3/ Lissie Formation in Baker (1964), Wesselman (1965 and 1967), Sandeen (1968), and Anders and others (1968); and Bentley and Montgomery Formations in Wilson (1967) and Tarver (1968a and 1968b).

4/ Pllocene (?).

5/ Shown as the Lagarto Clay of Miocene (?) age in Baker (1964) and Wesselman (1967).

unit have been mapped as the Alta Loma Sand of Rose (1943). In Orange County (Wesselman, 1965), the sands were mapped together as the "middle" aquifer.

In much of the updip (northwest) parts of Chambers and Jefferson Counties, the lower unit of the Chicot thins and loses much of the sand that is present downdip. Much of this loss is due to wedging of the unit, but some of the loss is due to facies changes.

Upper Unit

The upper unit of the Chicot consists of a basal sand overlain by clay. Most of the sand is part of the Montgomery Formation and can be traced into the outcrop of this geologic unit. The uppermost overlying clay is Beaumont, but in many places clay of the Montgomery Formation is also present.

No criteria other than the mapping of terrace levels have been developed for separating the Beaumont sands or sands of Holocene age from the underlying sands of the Montgomery Formation. The basal sand of the upper unit of the Chicot may be correlated with the "200-foot" sand of Calcasieu Parish, Louisiana (Harder, 1960).

SOURCE AND OCCURRENCE OF GROUND WATER

The principal source of fresh ground water in Chambers and Jefferson Counties is precipitation. Most precipitation runs off and becomes streamflow or evaporates immediately. Only a small fraction of the rainfall infiltrates to the zone of saturation. The zone of saturation is the zone below the water table where the interstices in the rocks are filled with water. Much of the penetrating water is rapidly returned to the atmosphere by evaporation or transpiration. A large percentage of the water that reaches the zone of saturation in the aquifers is rapidly returned to the surface as spring flow, which supports the base flow of the streams of the area.

Ground water occurs in aquifers. An aquifer is a geologic formation, group of formations, or part of a formation that is water bearing. An aquiclude is an impermeable or relatively impermeable bed that may contain water but is incapable of transmitting an appreciable quantity.

The water in an aquifer exists under one of two conditions, water table or artesian. Under water-table conditions, the water contained in the aquifer is under atmospheric pressure only. The water table is free to rise or fall in response to changes in the volume of water stored. A well penetrating an aquifer under water-table conditions fills with water to the level of the water table.

Artesian conditions occur when an aquifer is overlain by sediments of lower permeability that confine the water under hydrostatic pressure. Such conditions occur downdip from the outcrops of the aquifers. A well penetrating sands under artesian head (pressure) becomes filled with water to a level above the top of the aquifer. If the head (pressure) is great enough to raise the water to a level higher than the top of the well, the water flows. The height above the aquifer that the water will rise in a well is equivalent to the pressure head in the aquifer.

The water in the aquifers moves under the influence of gravity from areas of recharge to areas of discharge. The average velocity of movement is slow, less than a foot a day, except in the immediate vicinity of large wells or springs.

Discharge of ground water occurs both naturally and artificially. Natural means of discharge include evapotranspiration, spring flow, and upward seepage through clays. Artificial discharge is accomplished by pumping from wells; by pumping from excavations that intersect the water table; or by drainage that results when ditches are cut into and below the water table.

RECHARGE, MOVEMENT, AND DISCHARGE OF GROUND WATER

Before man began developing ground water in the Gulf Coast regions, the deeper aquifers had a higher head than the more shallow ones. The original higher piezometric head on the deeper aquifer systems was caused by the outcrops of the deeper aquifers being topographically higher. Downdip from the outcrops, movement of water was generally southeastward, in the direction of the hydraulic gradients, toward areas of natural discharge.

In much of the area, continuous clay beds confined the water, and the only avenue of discharge was upward through the clays. However, in some areas of low altitude, the aquifer sands are not overlain by clay, and fresh water was discharged through the sands. One such area is located between Smiths Point and Monroe City, 6 miles east of Anahuac, in Chambers County and another in the Pine Island Bayou and Neches River lowlands north and east of Beaumont. Much of the artesian fresh water that entered from surrounding counties was discharged as spring flow or seepage in these and similar areas.

The interconnection of the aquifers along the sides of the shallow piercement-type salt domes also provide avenues of discharge. Interconnection is indicated by electric logs and by water-quality data in the vicinity of Barbers Hill, Lost Lake, Moss Bluff, Fannett, Big Hill, and Spindletop Domes (Figure 3).

Originally, fresh and saline waters moved toward these domes under sufficient artesian heads to cause water to flow above land surface. Much of this water was, or became, salty as it passed adjacent to the domes from the lower aquifers to the upper aquifers. Interconnection of the aquifers allowed this deeper and usually more saline water with its higher piezometric head to rise and mix with the fresher water in the upper aquifers. A generalized illustration showing ground-water movement near domes was published by Hanna (1958, p. 11). It is reproduced here as Figure 4.

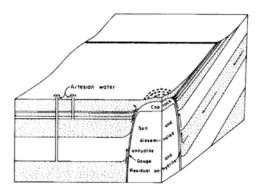


Figure 4.—Idealized Block Diagram Illustrating Ground-Water Circulation Around Salt Domes

Since the development of the ground-water resources of this region began in the 1800's, the subsurface circulation of the water has been changed repeatedly, and new recharge-discharge relationships have been established. Because of ground-water development, water levels declined. Cones of depression around each well altered the natural flow pattern, and water now moves from all directions into these centers of pumping. Withdrawals from the aquifers in Harris and Orange Counties have established large regional cones of depression that extend into Chambers and Jefferson Counties. A smaller cone of depression has been established by pumping in the Winnie-Hamshire area.

The cones of depression have lowered the piezometric surface below land surface in the artesian aquifers at all observed points, and below sea level in much of the area. Because of this alteration, the previously described areas of discharge have, or will soon become, areas of recharge to the underlying aquifers.

Specifically, some parts of the upper unit of the Chicot aquifer in Chambers and Jefferson Counties which formerly discharged water as springs and seeps are probably now recharged with fresh water through these outcrops of sand within the counties. Probably most of the lower unit of the Chicot and the Evangeline aquifers

are still recharged through outcrops in adjoining or nearby counties.

HYDRAULIC CHARACTERISTICS OF THE AQUIFERS

"The worth of an aquifer as a fully developed source of water depends largely on two inherent characteristics: its ability to store and its ability to transmit water" (Ferris and others, 1962, p. 70). These characteristics are measured by the coefficients of storage and transmissibility.

The coefficient of storage is important in any calculation of the quantity of water that can be obtained from an aquifer; but the availability of the water, especially in an artesian aquifer, depends primarily on the ability of the aquifer to transmit water. The coefficient of permeability is a measure of that ability and is defined as the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a unit-hydraulic gradient (1 foot per foot) at a temperature of 16°C (60°F). In field practice the adjustment to the standard temperature of 16°C (60°F) is commonly disregarded, and the permeability is then understood to be a field coefficient at the prevailing water temperature. The coefficient of transmissibility is the product of the field coefficient of permeability and the saturated thickness of the aquifer.

The specific capacity of a well is its yield per unit drawdown and can be theoretically related to transmissibility. It is expressed in gallons per minute per foot of drawdown. The measured specific capacity may differ from the computed theoretical specific capacity of a well for one or more reasons. Improper well construction and development, screen losses, unfavorable local geologic conditions, screening only part of the available aquifer-all are factors that will decrease the measured specific capacity. On the other hand, in some wells the effective diameter of the well may be increased by proper development. As a result, the measured specific capacity can be larger than the theoretical. Wood and others (1963, p. 40), referring to the Gulf Coast region, reported that "... the measured specific capacities of most wells in the region are smaller than the theoretical, indicating that many of the sands in the gravel-packed zone are poorly connected to the interior of the screen so that screen losses are considerable during pumping."

The coefficients of storage and transmissibility of the aquifers were determined by aquifer tests made in wells in Chambers and Jefferson Counties. The test data were analyzed by the Theis non-equilibrium method as modified by Cooper and Jacob (1946, p. 526-534), or by the Theis recovery method (Wenzel, 1942, p. 95-97). The results of the tests and specific capacities of the wells are shown in Table 2. None of the wells are completed in a full section of an aquifer, therefore the

values in the table are less than the aquifer's total capability.

The coefficients of transmissibility and storage may be used to predict drawdowns in water levels caused by pumping. The theoretical relation between drawdown and distance from the center of pumping for different coefficients of transmissibility is shown on Figure 5. The calculations of drawdown are based on a withdrawal of 1 mgd (million gallons per day) for 1 year from an aquifer having coefficients of transmissibility and storage as shown and assuming the aquifer has infinite areal extent. For example, if the coefficients of transmissibility and storage are 50,000 gpd (gallons per day) per foot and 0.001, respectively, the drawdown or decline in the water level would be 12 feet at a distance of 1 mile from a well or group of wells discharging 1 mgd for 1 year. If the coefficients of transmissibility and storage are 5,000 gpd per foot and 0.0001, respectively, the same pumping rate for the same time would cause 84 feet of decline at the same distance.

Figure 6 shows the relation of drawdown to distance and time as a result of pumping from an artesian aquifer with characteristics similar to those found in the artesian aquifers of Chambers and Jefferson Counties. To prepare these curves, it was assumed that the aquifers had infinite areal extent. This illustration shows that the rate of drawdown decreases with time. For example, the drawdown at 100 feet from a well is 11 feet after 1 mgd has been pumped for 1 year, and the drawdown is about 15 feet after 1 mgd has been pumped for 100 years. The total drawdown at any one place within the cone of depression (or influence) of several wells would be the sum of the influences of the several wells. The equilibrium curve illustrates the timedrawdown relation when a line source of recharge is 25 miles from the point of discharge.

Figure 7 shows the relation of drawdown to distance and time as a result of pumping from a water-table aquifer with characteristics similar to small parts of the upper unit of the Chicot aquifer. Again, infinite areal extent of the aquifer is assumed. The drawdown is less than that in an artesian aquifer because, under water-table conditions, the coefficient of storage is larger.

Interference between wells may cause a decrease in yield of the wells, or an increase in pumping costs, or both. If the pumping level declines below the top of the aquifer screened, the saturated thickness of the aquifer decreases and the result is a decrease in the yield of the well.

Aquifer tests were run on 10 wells tapping the lower unit of the Chicot aquifer in Chambers and Jefferson Counties. Coefficients of transmissibility ranged from 5,200 to 401,000 gpd per foot and coefficients of permeability ranged from 108 to 1,670 gpd per square foot. The highest permeability was

determined from a test of a saline-water well completed in the lower most massive sand in the lower unit of the Chicot. Specific capacities ranged from 3.4 to 32.5 gpm (gallons per minute) per foot. The coefficient of storage in the lower unit of the Chicot ranged from 0.0004 to 0.0037.

Tests of 9 wells completed in the upper unit of the Chicot showed the following ranges in coefficients: transmissibilities from 10,800 to 29,800 gpd per foot; permeabilities from 174 to 596 gpd per square foot; and specific capacities from 1.7 to 11 gpm per foot. Two determinations of the coefficient of storage were 0.0007 and 0.0002.

Tests were made in two wells completed in the Evangeline aquifer. The coefficients of transmissibility were 32,000 and 36,000 gpd per foot and coefficients of permeability were 244 and 327 gpd per square foot. The coefficient of storage was 0.00003. The specific capacity of one of the wells was 16.2 gpm per foot. These results compare favorably with those observed in nearby areas. Tests of the "heavily pumped layer" (Evangeline aquifer) in the Houston district show the average coefficient of permeability to be about 250 gpd per square foot, and tests in Jasper and Newton Counties northeast of the report area showed an average of 260 gpd per square foot.

PRODUCTION AND USE OF GROUND WATER

The first production of ground water in Chambers and Jefferson Counties was probably from holes dug into beach ridges by Indians who hunted and fished along the Gulf Coast. Early permanent settlers of the region utilized mostly shallow wells. Deussen (1914) reported many deep, fairly large wells, most of which flowed. These wells had been drilled in the decades preceding and following 1900. Oil exploration together with the development of rice irrigation in southeastern Texas and southern Louisiana caused many wells to be drilled. The extent and quality of the ground water were fairly well known at that time.

Penn Livingston and G. H. Cromack (written commun., 1943) reported that in Jefferson County, production of ground water, stimulated by oil field development, irrigation, and the construction of refineries, rose to a peak of about 25 mgd in 1926. Much of this development was in areas underlain mostly by slightly or moderately saline water. The poor quality of much of the water probably discouraged its use as production decreased to about 10 mgd in 1927. In 1941, the combined production in Chambers and Jefferson Counties was probably a little less than 8.5 mgd. Total production of ground water in both counties decreased to about 5 mgd in 1948. Development of the upper unit of the Chicot aquifer in the Winnie-Hamshire, Anahuac, and Hankamer areas; of the Evangeline and Chicot

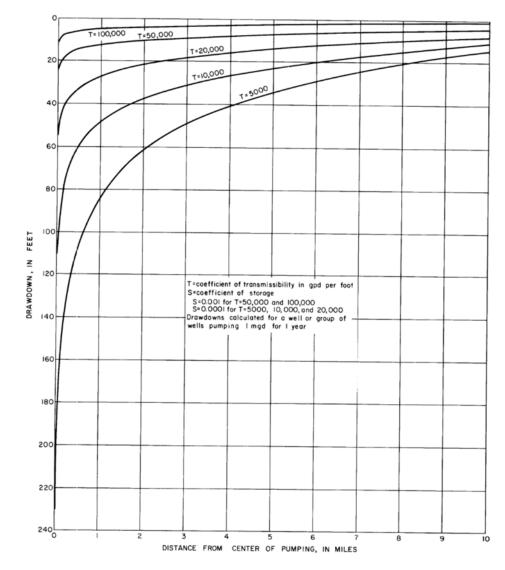


Figure 5.—Relation of Drawdown to Transmissibility and Distance

aquifers in the Mont Belvieu-Baytown area; and of the lower Chicot in the Beaumont-Port Arthur area raised the production rate to 8.6 mgd by 1965.

Most of the ground water developed prior to World War II was taken from the lower unit of the Chicot aquifer in the Beaumont-Port Arthur area, whereas production in 1965 was divided about equally among the upper unit of the Chicot, lower unit of the Chicot, and the Evangeline. The principal areas of

production are the Mont Belvieu-Baytown area of western Chambers County, the Winnie-Hamshire area of Chambers and Jefferson Counties, and the Beaumont-Port Arthur area of Jefferson County. Other sites where significant ground-water withdrawals occur include the Big Hill Dome, the flank of High Island Dome, Redfish Reef in Galveston Bay, Hankamer, and Anahuac. The locations of wells in Chambers and Jefferson Counties and adjacent areas are shown on Figure 24.

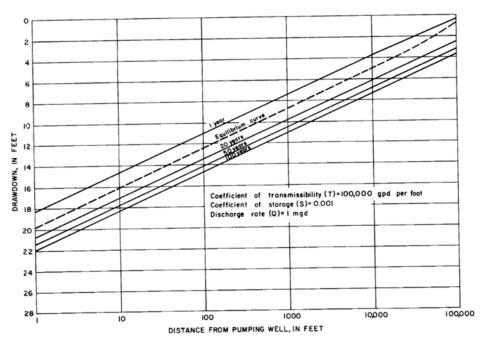


Figure 6.—Relation of Drawdown to Distance and Time as a Result of Pumping Under Artesian Conditions

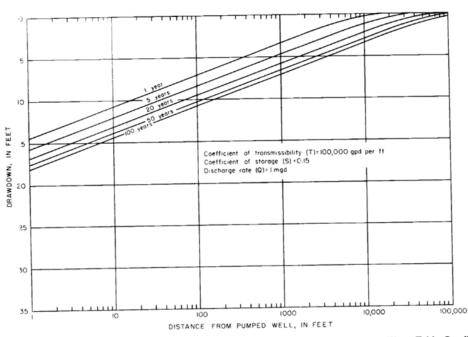


Figure 7.—Relation of Drawdown to Distance and Time as a Result of Pumping Under Water-Table Conditions

Table 2.—Summary of Aquifer Tests

WELL	DATE	COEFFICIENT OF TRANSMISSIBILITY (GPD PER FT)	COEFFICIENT OF PERMEABILITY (GPD PER FT ²)	COEFFICIENT OF STORAGE	SPECIFIC CAPACITY (GPM PER FT OF DRAWDOWN)	REMARKS
		UPPER	UNIT OF CHICOT AQUIFE	R		
DH-64-11-801	Dec. 3, 1955	15,000	375	-	11	100 minutes pumping time; recovery pumped well.
DH-64-12-102	July 12, 1966	29,800	*596	-	7	Recovered 100 minutes after 28 hours pumping.
DH-64-13-601	Sept. 16, 1953	10,800	360	-	5.3	5-hour recovery after 48 hours pumping.
	Oct. 2, 1953	11,800	358	-	8.3	5-hour recovery after 51 hours pumping.
PT-64-14-407	June 1, 1945	26,000	222	-	6.2	Recovery after 24 hours pumping.
PT-64-14-408	June 21, 1945	17,900	174	7.0×10 ⁻⁴	-	Drawdown
PT-64-14-409	June 1, 1945	21,000		2.0×10 ⁻⁴		observation well.
PT-64-15-704	Sept. 22, 1966	21,300	207	2.0x10-4	-	Do.
PT-64-15-705	-	21,600	216	-	1.7	observation well. Recovery pumped well; 23-hour test.
		LOWER	UNIT OF CHICOT AQUIFER			
PT-61-64-501	1941	55,200	502	-	-	Recovery after unknown period of pumping.
PT-61-64-502	Mar. 22, 1966	13,100	108	-	8.7	40-hour recovery following 27-hour drawdown.
PT-61-64-505	Mar. 21, 1966	18,000	310	4×10 ⁻⁴	-	Observation well; drawdown.
	Mar. 24, 1966	183,000	915	-	32.5	Recovery pumped well after 22 hours pumping.

Table 2.—Summary of Aquifer Tests—Continued

WELL	DATE	COEFFICIENT OF TRANSMISSIBILITY (GPD PER FT)	COEFFICIENT OF PERMEABILITY (GPD PER FT ²)	COEFFICIENT OF STORAGE	SPECIFIC CAPACITY (GPM PER FT OF DRAWDOWN)	REMARKS
		LOWER	UNIT OF CHICOT AQUIFER	R—Continued		
PT-61-64-506	Mar. 24, 1966	163,000	906	1.06×10 ⁻³	-	Drawdown test in observation well.
PT-61-64-509	Mar. 21, 1966	30,800	296	7×10 ⁻⁴	-	Drawdown observation well.
DH-64-09-301	Nov. 3, 1966	78,200	821	-	25.8	25 hours recovery after 27 hours pumping.
DH-64-09-302	do	80,000	762	3.7×10·3	-	Recovery of observation well.
DH-64-26-701	Nov. 29, 1966	5,200	157	-	3.4	5-hour recovery after 24 hours pumping.
DH-64-29-502	Aug. 22, 1966	401,000	1,670	-	11.0	130-minute recovery after 24 hours pumping.
		LOWER UNIT OF	CHICOT AQUIFER AND EVA	ANGELINE AQUIFER		
DH-64-10-401	Aug. 3, 1955	45,000	-	-	23.2	Recovered 70 minutes after 5 days pumping.
			EVANGELINE AQUIFER			
DH-64-09-305	May 27, 1966	32,000	244	-	16.2	300-minute recovery of constantly pumped well.
DH-64-09-307	do	36,000	327	3.0×10 ⁻⁵	-	Recovery observation well.

Permeability based on screen length.

The production of water from wells in Chambers and Jefferson Counties in 1965 was as follows (figures are in mgd):

		CLASS OF USI	E	
COUNTY	INDUS- TRIAL	MUNICIPAL	IRRIGA- TION	TOTAL*
Jefferson	3.1	1.0	.5	4.6
Chambers	2,0	1.0	1.0	4.0
Total*	5.1	2.0	1.5	8.6

Figures are approximate because some of the production was

About 30 percent of this production (about 2.5 mgd) was slightly or moderately saline water used by industry.

The high salinity of much of the ground water has restricted its use. Consequently, the primary sources of water have been the Neches and Trinity Rivers, and most of the needs of industry, irrigation, and large municipalities in the area from the mid-1920's until the 1950's were met from these sources. However, the consistent quality and uniform temperature of ground water was especially desirable for some uses and as early as the 1920's, ground water produced from the lower unit of the Chicot aquifer in Orange County was imported by a refinery in the Port Arthur area.

The total estimated use of ground water (including imported ground water) in Chambers and Jefferson Counties in 1965 was approximately 18.6 mgd. Of this, 10 mgd was fresh water produced from wells in Hardin and Orange Counties and imported by the city of Beaumont and industries in Beaumont and Port Arthur. In 1958, Beaumont started supplementing its surface-water supply with ground water from a well field tapping the Evangeline aquifer in Hardin County, and in 1965 obtained 6 mgd from this field. According to Underwood Hill, Water Superintendent of Beaumont (personal commun., July 8, 1967), the city of Beaumont plans to expand its usage of ground water to 20 mgd by 1980.

Two industries in Beaumont and Port Arthur in 1965 imported 4 mgd of ground water produced from the lower unit of the Chicot aquifer in Orange County. One industry in Port Arthur has been importing about 0.5 mgd since the 1920's. The other developed its supply in 1962.

Because sufficient quantities of fresh ground water are not available locally and large supplies of fresh

ground water are available nearby, further importation of fresh ground water from outside the counties is probable.

WATER LEVELS

Water-level data are presented by hydrographs and maps. Data gathered during the 1941-42 inventory and during inventories since 1942 were used in the preparation of Figures 8 and 9. Water-level measurements are presented in Tables 4 and 6.

Long-term records of water levels indicate the magnitude of the water-level changes that have occurred in the Chicot aquifer. Measurements show that in well PT-64-06-401 (Figure 9), the differences in the high and low water levels were less than 2 feet during the period of record 1941-66. The largest change in water levels occurred in the lower unit of the Chicot aquifer in western Chambers County in the area adjacent to the city of Baytown, where water levels dropped more than 90 feet during the period 1941-66. The 1966 measurements, compared with the early reports of flowing wells, indicate that water levels have declined at least 150 feet. No long-term water-level records are available for the Evangeline aquifer. Water levels have possibly declined as much in the Mont Belvieu area as the decline recorded in the lower unit of the Chicot in the Baytown area.

Evangeline Aquifer

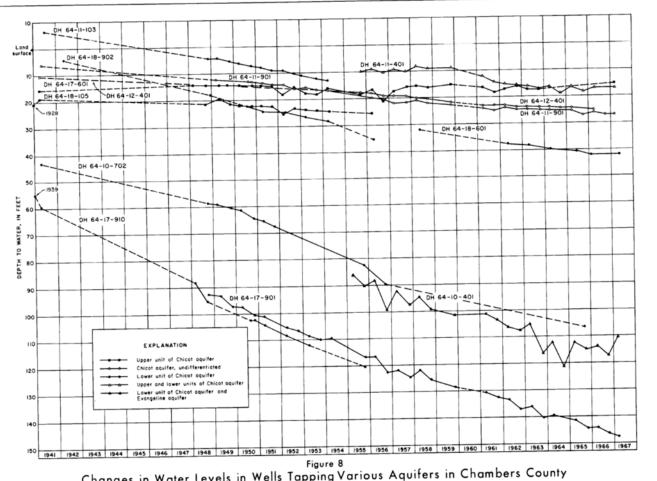
Water-level measurements in wells completed in the Evangeline aquifer in Chambers and Jefferson Counties date back only a few years. The levels that have been measured are in the Mont Belvieu area, and these closely approximate the levels in the lower Chicot in the same area.

Chicot Aquifer

The water levels and other criteria used to separate the upper and lower units of the Chicot aquifer in most of Chambers and Jefferson Counties were not sufficient to separate the two units in a large area centered near the eastern edge of Trinity Bay in Chambers County. Inspection of the maps (Figures 10 and 11) and of the hydrographs of wells (Figure 9) shows that the declines and seasonal fluctuations of water levels have been less in this area than in the areas to the east and west of it.

Lower Unit

The map of the 1941 and 1966 water levels in the lower unit of the Chicot aquifer (Figure 10) shows large depressions in western Chambers County as early as



Changes in Water Levels in Wells Tapping Various Aquifers in Chambers County

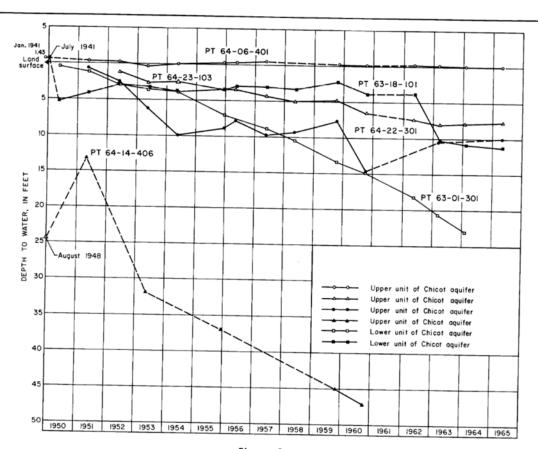


Figure 9
Changes in Water Levels in Wells Tapping the Upper and Lower Units of the Chicot Aquifer in Jefferson County

1941. These depressions were caused by heavy pumping in Galveston and Harris Counties. Contour lines on the map indicate that water in the lower unit of the Chicot aquifer was moving from western Chambers County into Harris and Galveston Counties in 1941. The direction of movement in 1966, as indicated by the map, is still the same, but the hydraulic gradient and the rate of movement have increased.

The effect of pumping from the lower Chicot in the Beaumont-Port Arthur-Orange area of eastern Jefferson and southern Orange Counties before 1941 is reflected in the shape of the contours. By 1966, the pumping center of this area was well defined. Pumping by chemical industries, municipalities, and from irrigation wells in Orange County caused a regional cone of depression that is reflected by the contours (Figure 10). The cone of depression extends into eastern Jefferson County, consequently, the movement of the water in this area is from Jefferson County into Orange County.

Upper Unit

The map of water levels in the upper unit of the Chicot aquifer in 1941 and 1966 (Figure 11) does not indicate any large regional centers of withdrawals in 1941. However, pumping depressed the water surface below sea level in areas a few miles west of Port Arthur and near Groves in Jefferson County and in the vicinity of Houston Point and Wallisville in Chambers County.

By 1966, the industrial, municipal, and irrigation withdrawals in the vicinity of Winnie had created a cone of depression (Figure 11) in eastern Chambers and western Jefferson Counties.

RELATION OF WATER-LEVEL DECLINES TO LAND-SURFACE SUBSIDENCE

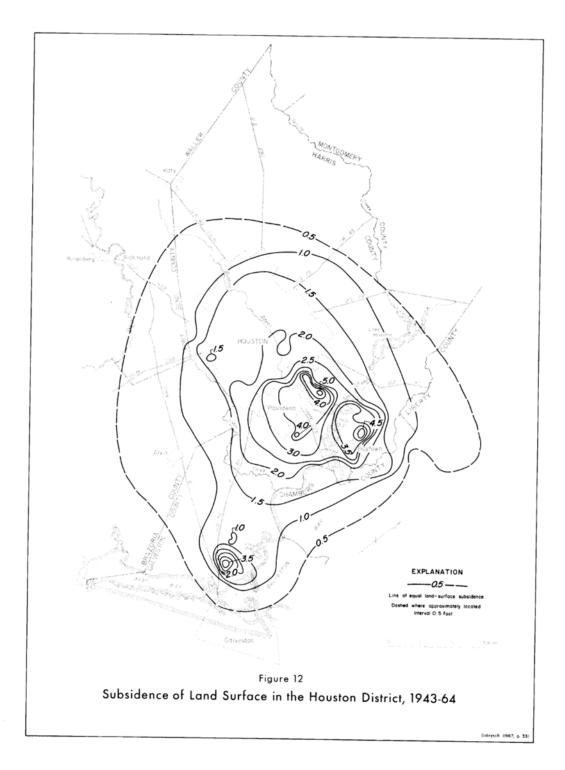
The withdrawal of water from an artesian aquifer results in an immediate decrease in hydraulic pressure which partially supports the weight of the overlying rocks. With reduction in pressure, an additional load is transferred to the skeleton of the aquifer and a pressure difference between the sands and clays causes water to move from the clays to the sands. The entire process results in compaction of the sediments, most of which takes place in the clays. Because of the compaction, the land surface subsides.

Regional subsidence in the Texas Gulf Coast is due principally to the extraction of water, although subsidence may also occur because of the removal of oil and gas. In addition to other factors, the amount of

decline in artesian head and the thickness of clay are important to total subsidence. R. K. Gabrysch (oral commun., 1967) found that in the Houston district, which includes the western part of Chambers County, subsidence ranged from 0.5 foot to 1.5 feet for each 100 feet of artesian head decline. The ratio of 0.5 foot subsidence per 100 feet head decline occurred in an area where the section contained about 40 percent clay. As the clay percentage increased, the ratio of subsidence to head decline increased. In the area of 1.5 feet subsidence per 100 feet head decline, clay composed about 70 percent of the section.

Winslow and Wood (1959) show that lowering of the artesian head by development of ground water has resulted in subsidence of the land surface in most of the upper Gulf Coast region of Texas. They mapped the extent of this subsidence by comparing measurements of bench-mark altitudes made at different times by the U.S. Coast and Geodetic Survey. Their map shows that the land surface subsided more than 0.5 foot in western Chambers County between 1918 and 1954. For this period of time, their map showed less than 0.25 foot subsidence for most of the rest of Chambers and Jefferson Counties. A small area in eastern Jefferson County had subsided more than 0.25 foot and an extremely local area, in the vicinity of the Spindletop Dome, subsided more than 1 foot. The areas that subsided, with the exception of the Spindletop Dome, are areas in which artesian head has declined. Subsidence at Spindletop is related to the production of oil. Extremely localized subsidence sometimes takes place when sulfur is removed from the cap rock of the salt domes by the Frasch process. A depression over 15 feet deep, which is periodically enlarging and deepening, is present at the Moss Bluff Dome on the Liberty-Chambers County line just east of the Trinity River. The Frasch process of removing sulfur has been initiated at the Fannett and Spindletop Domes in the last decade but noticeable subsidence that could be attributed to this cause was not found during this study.

The latest releveling of bench marks by the U.S. Coast and Geodetic Survey was in 1964, but only a part of the area mapped by Winslow and Wood was releveled. Gabrysch (1967) showed that subsidence in the western part of Chambers County has continued. Figure 12, a contour map of subsidence in the Houston district, shows that a maximum of 2 feet of subsidence occurred at the eastern edge of the city of Baytown (along the western edge of Chambers County) during the period 1943-1964. East of the area shown on Figure 12, regional subsidence through 1967 probably has been mostly less than 0.5 foot. In small areas, such as Lost Lake, Moss Bluff (north of Lost Lake), Hankamer, High Island, Big Hill (8 miles southeast), and Fannett, subsidence due to the removal of oil and gas probably is greater than 0.5 foot.



A sufficient number of bench marks, necessary to determine subsidence in detail, is not available in much of Chambers and Jefferson Counties.

WELL CONSTRUCTION

Generally, when a well is to be constructed for public supply or industrial use in a new location, a test hole is drilled to the depth desired. Formation samples are collected during drilling, and after completion of the test hole, an electrical log is run. The log is used to determine the occurrence of sands and to indicate in general the quality of water they contain. Some of these test holes are used to collect water samples for chemical analysis and to measure the water-yielding properties of the sands.

If favorable ground-water conditions are indicated by the data collected, the test hole is usually reamed to the top of the first sand that is to be screened; surface casing is then installed and cemented into place. The diameter of the surface casing in most large-capacity wells in Chambers and Jefferson Counties ranges from 12 to 20 inches.

The section to be screened is then reamed with the largest drilling bit that can pass through the surface casing. The hole is then underreamed by a device that expands and cuts a hole larger than the diameter of the surface casing, usually to a diameter of 30 inches. Blank pipe and screen are then installed with part of the blank pipe extending up into the surface casing. The bottom of the screen is closed off with a back-pressure valve that permits the use of fluid to keep the hole clean during emplacement of the screen, but prevents water, sand, or gravel from entering through the bottom. Gravel or sand is then pumped into the annular space between the screen and the well bore. The gravel reservoir--the space between the bottom of the surface casing and the top of the blank pipe-is also filled with gravel. The construction of a typical industrial or public-supply well is shown on Figure 13.

Usually the screen is steel pipe, 6 to 14 inches in diameter, that has been perforated and wrapped with stainless steel wire. Where corrosion is a problem, the pipe may be stainless steel. Generally the openings in the screen, which are as much as 0.05 inch wide, are larger than the sand particles in the formation but smaller than those of the gravel envelope. Blank pipe of the same diameter as the screen is used to separate screens and is positioned opposite clay beds in the producing intervals.

The well may be developed by surging, swabbing, pumping, back-washing, and by chemical treatment until the specific capacity of the well indicates complete development and the sand-water ratio is satisfactory. The final production test usually lasts from 4 to 24 hours, during which samples of water for chemical and bacterial analyses are collected.

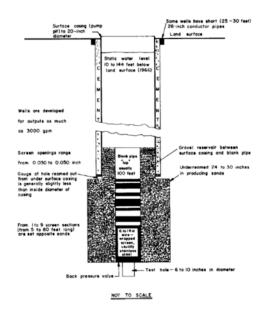


Figure 13.-Construction of Industrial and Public Supply Wells

Some large irrigation wells have been constructed in a similar manner, with slotted pipe being used instead of wrapped screen. More commonly, however, a large diameter hole is drilled from the surface to the finished depth, no cement is used, and gravel is placed outside the entire casing string. In some smaller diameter irrigation wells, screen is selected to fit the sands encountered, and no gravel is used.

The size and type of pump installed on the large-capacity wells depend upon the pumping lift and the quantity of water needed. The larger public-supply and industrial wells have high-capacity, deep-well turbine pumps powered by electricity. Irrigation wells are equipped with the same type of pumps but are powered by diesel or gas motors.

Although shallow dug wells, usually 30 to 36 inches in diameter, have been constructed in a few localities, most of the modern, small-capacity wells used for domestic or industrial supply are drilled wells that have been completed with a single screen.

A variety of screen types are available. Stainless steel and plastic have become the most widely used in Chambers and Jefferson Counties because of their resistance to corrosion. Plastic is coming into widespread use as the material for conductor pipe and screens in the small and relatively shallow wells. Stainless steel screen is used in the large wells.

Oil-rig drill pipe is used as casing in most of the water-supply wells drilled in the oil fields of Trinity Bay. Because of its thick walls, the time it takes the pipe to corrode and the well to fail is extended.

Various types of pumps are used on small-capacity wells. New small wells are usually equipped with submersible pumps, whereas older wells, particularly those in areas of lowered artesian head, are usually equipped with the deep jet-type pumps. Windmills in conjunction with cylinder-type pumps are still used to lift water for livestock use, particularly in remote locations, but many windmills are being replaced by electric-powered pumps.

QUALITY OF GROUND WATER

The chemical constituents of ground water originate principally from the soil and rocks through which the water has moved. Table 3 lists many of the chemical constituents and properties of water and discusses their source and significance. The chemical analyses of water from selected wells in Chambers and Jefferson Counties are given in Table 7.

The quality of water commonly determines its suitability for use. A general classification of water, according to dissolved-solids content in mg/l (milligrams per liter), is as follows (modified from Winslow and Kister, 1956, p. 5):

DESCRIPTION	DISSOLVED-SOLIDS CONTENT (MG/L)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

Maps showing the base of fresh water, the base of slightly saline water, and the thickness of sands containing fresh water are included in this report as Figures 16, 17, 18, and 19. Analysis of these maps and the cross sections (Figures 25 through 28) shows that most of the water underlying Chambers and Jefferson Counties is slightly or more than slightly saline.

Suitability for Public Supply

The U.S. Public Health Service (1962, p. 7) has established standards for the chemical quality of water to be used on common carriers engaged in interstate commerce. These standards, which are commonly used in evaluating public water supplies, are included in Table 3.

According to the U.S. Public Health Service (1962, p. 41), the optimum fluoride level for a given community depends on climatic conditions, because the amount of water (and consequently the amount of fluoride) ingested is influenced primarily by air temperature. In Chambers and Jefferson Counties, the optimum concentration based on the annual average of maximum daily air temperature of 26.1°C (79°F) at Beaumont is 0.8 mg/l. Presence of fluoride in average concentrations greater than twice the optimum value, or 1.6 mg/l, would constitute grounds for rejection of the supply. Excessive concentrations of fluoride are present in the water from some wells in Chambers and Jefferson Counties.

The 1941-42 well inventory and water-sampling program (Livingston and Cromack, 1942a, 1942b) included analyses of water from shallow wells (9 to 47 feet deep) in the upper unit of the Chicot aquifer that showed more than the recommended limit (45 mg/l) of nitrate concentration. However, the nitrate concentration in water from all deeper wells sampled at that time was less than the recommended limit. Samples from only a few shallow wells were collected in 1966. Of these, only one well (PT-64-08-403), 27 feet deep, yielded water with an excessive amount of nitrate. Also, the deeper wells sampled in 1966 did not have excessive nitrates. The presence of nitrates in excess of the limit in the shallow wells suggests pollution by sewage or by other organic material.

Water having a chloride content exceeding 250 mg/l may have a salty taste, and sulfate in water in excess of 250 mg/l may produce a laxative effect. Much of the water produced in Chambers and Jefferson Counties has a chloride content greater than 250 mg/l. Excessive amounts of sulfates occur in water in some shallow sands and in some of the deeper sands near the shallow salt domes.

About half of the samples analyzed for iron showed that this constituent was present in excess of the 0.3 mg/l limit. A relationship between iron concentration and depth of the well was not established, and it was not determined whether the iron occurred naturally or as a product of interaction between the water and the metal parts of the well.

Suitability for Industrial Use

The suitability of water for industrial use is dependent upon the process in which the water is used. Water for cooling and boiler uses should be noncorrosive and relatively free of scale-forming constituents, of which hardness and silica are the most important.

The silica content (Table 7) in water from the aquifers in these counties ranged from 5.3 to 38 mg/l. Moore (1940, p. 263) suggested the following allowable concentration of silica in boilers operating at various

CONSTITUENT OR PROPERTY	SOURCE OR CAUSE	SIGNIFICANCE
Silica (SIO ₂)	Dissolved from practically all rocks and soils, commonly less than 30 mg/l. High concentrations, as much as 100 mg/l, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 mg/l of iron in surface waters generally indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish- brown precipitate. More than about 0.3 mg/istains laundry and utensils reddish-brown. Objectionable for food processing, tex- tile processing, beverages, ice manufacture, brewing, and other processes. U.S. Public Health Service (1962) drinking-water standards state that iron should not exceed 0.3 mg/i. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO ₃) and carbonate (CO ₃)	Action of carbon dioxide in water on carbonate rocks such as lime- stone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon dioxide gos. In combination with calcium and magnesium, cause carbon- ate hardness.
Sulfate (SO ₄)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. U.S. Public Health Service (1962) drinking-water standards recommend that the sulfate content should not exceed 250 mg/l.
Chloride (CI)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. U.S. Public Health Service (1962) drinking-water standards recommend that the chloride content should not exceed 250 mg/l.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal sup- plies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enable calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual. (Maier, 1950)
Nitrate (NO3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution. U.S. Public Health Service (1962) drinking-water standards suggest a limit of 45 mg/l, Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing inter-crystalline cracking of boiler steel, it encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids	Chiefly mineral constituents dis- solved from rocks and soils. Includes some water of crystalli- zation.	U.S. Public Health Service (1962) drinking-water standards recommend that waters containing more than 500 mg/l dissolved solids not be used if other less mineralized supplies are available. Waters containing more than 1000 mg/l dissolved solids are unsultable for many purposes.
Hardness as CaCO3	In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. Waters of hardness as much as 60 ppm are considered soft; 61 to 120 mg/l, moderately hard; 121 to 180 mg/l, moderately more than 180 mg/l, very hard.
Specific conductance (micromhos at 25°C)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydrox- ides, and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.

pressures: less than 150 psi (pounds per square inch), 40 mg/l; 150-250 psi, 20 mg/l; 250-400 psi, 5 mg/l; and more than 400 psi, 1 mg/l.

A classification commonly used with reference to hardness is as follows: 60 mg/l or less, soft; 61 to 120 mg/l, moderately hard; 121 to 180 mg/l, hard; and more than 180 mg/l, very hard. If water used in steam boilers has more than 75 mg/l hardness as calcium carbonate, it should be treated to prevent the formation of scale (American Society for Testing Materials, 1959, p. 24). In high-pressure boilers, the tolerance is much less than 75 mg/l. Suggested water-quality tolerances for a number of industries are summarized by Hem (1959, p. 253) from Moore (1940). Although the hardness of the water (Table 7) ranges from soft to very hard, most of the water sampled was moderately hard or hard.

Large amounts of water are used to dissolve salt from salt domes to create caverns for storage of gas; the quality of water used for this purpose is not important. In some chemical processes, water of uniform chemical quality, clarity, and temperature is necessary, and even slightly or moderately saline ground water often meets these conditions better than surface water. In waterflooding operations, saline ground water is often preferred because of its compatability with fluids in the formation and because it is usually organically pure and sediment-free.

The temperature of water is often of great importance to industry and to other users. The temperature of ground water near the land surface is approximately the same as the mean annual air temperature of the region, 20.9°C (69.7°F) at Beaumont, but increases with depth. The lowest temperature of ground water recorded during the study, from a well 159 feet deep, was 22°C (71°F). The highest water temperature recorded during the study, from a well 1,255 feet deep, was 29.2°C (84.6°F). Temperature of ground water at any particular depth remains relatively constant throughout the year.

Suitability for Irrigation

The suitability of water for irrigation depends on the chemical quality of the water and on other factors such as soil texture and composition, types of crops, irrigation practices, and climate. The most important chemical characteristics pertinent to the evaluation of water for irrigation are: the proportion of sodium to total cations—an index of the sodium hazard; total concentration of soluble salts—an index of the salinity hazard; RSC (residual sodium carbonate); and the concentration of boron.

A system of classification commonly used for judging the quality of water for irrigation was proposed by the U.S. Salinity Laboratory Staff (1954, p. 69-82). This classification is based primarily on the salinity

hazard as measured by the electrical conductivity of the water and on the sodium hazard as measured by the SAR (sodium-adsorption ratio). Although this classification was used in Figure 14, it may not be directly applicable because of the high rainfall. Wilcox (1955, p. 15-16) stated that water would be safe for supplemental irrigation if its conductivity was less than 2,250 micromhos per centimeter at 25°C and if its SAR was less than 14. This classification does show that in Chambers and Jefferson Counties most water tested had a high to very high salinity hazard and a low to very high sodium hazard. However, of the 62 water samples represented on the diagram, 30 samples were within the safe limits for supplemental irrigation. Most of these samples were taken from the freshest portions of the aquifers and the 32 samples which showed the water to be probably unsafe for even supplemental irrigation are probably most representative of most of the water in the aquifers of Chambers and Jefferson Counties.

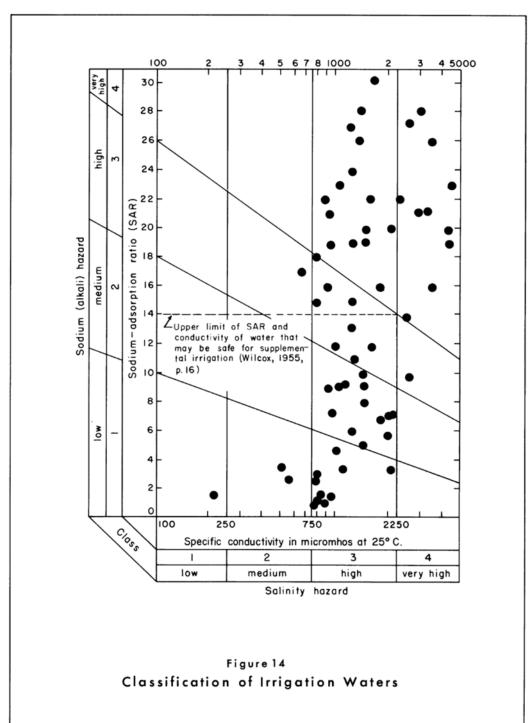
An excessive concentration of boron renders a water unsuitable for irrigation. Scofield (1936, p. 286) indicated that boron concentrations of as much as 1 mg/l are permissible for irrigating most boron-sensitive crops and that concentrations of as much as 3 mg/l are permissible for the more boron-tolerant crops. All but one analysis (Table 7) which list boron show a concentration less than 1 mg/l.

Another factor in assessing the quality of water for irrigation is the RSC of the water. Excessive RSC will cause water to be alkaline, and the alkaline water will cause organic material of the soil to dissolve. The affected soil, which may become grayish-black, is referred to as "black alkali". Wilcox (1955, p. 11) states that laboratory and field studies have resulted in the conclusion that water containing more than 2.5 me/l (milliequivalents per liter) RSC is not suitable for irrigation. Water containing from 1.25 to 2.5 me/l is marginal, and water containing less than 1.25 me/l RSC is probably safe. Correct irrigation practices and proper use of amendments to the soil might make possible the successful use of marginal water for irrigation. In the majority of the samples analyzed, the RSC was high, the maximum value being 9.31 me/l.

The high conductivity (salinity hazard) and the generally unfavorable SAR and RSC values shown in the analyses are probably among the factors responsible for the abandoning of numerous irrigation wells in Chambers and Jefferson Counties in the past.

RELATIONSHIP OF FRESH GROUND WATER TO SALINE GROUND WATER

Two distinct relationships between fresh and saline water are evident in the Chicot and Evangeline aquifers in Chambers and Jefferson Counties. The normal relationship is for the fresh water to float on the salt water because of the greater density of the latter. This



- 31 -

relationship is modified by the interbedding of sands and clays. Fresh water occurs at depths greater than 1,400 feet under these conditions in Chambers and Jefferson Counties.

The other relationship occurs in the vicinity of the salt domes. The domes are composed of about 90 to 95 percent rock salt and 5 to 10 percent impurities, most of which is anhydrite (Hanna, 1958, p. 7). These domes have penetrated the sands and clays and placed soluble salt in contact with the water in the aquifers.

Originally, the shallowest and most permeable aquifer, the Chicot, had the lowest artesian head. Saline water has entered the lower beds of the Chicot aquifer near the domes that penetrate it. Saline water has also deteriorated the quality of the water in the Evangeline aquifer, near these domes.

When water dissolved the salt near the top and along the sides of the domes, much of the impurities in the salt remained as residue. Most of this residue was left at the top of the domes, where it became the parent material for the cap rock. Portions of this anhydrite have been altered to gypsum, lime, and sulfur. The high sulfate concentrations found in the analysis of some water from the Chicot in the vicinity of the domes probably originates from processes taking place in the cap rock.

Figure 4, a block diagram and hydrologic section showing the relationship of the ground water and its quality to the Barber's Hill Dome at Mont Belvieu, indicates that the poorer quality water in the lower unit of the Chicot aquifer can be traced from the dome to the northeastern edge of Baytown (6 miles away). Electric logs indicate that a similar relationship exists in the Nome area of Jefferson County, south of the Sour Lake Dome in Hardin County.

Sands that crop out north of the Fannett Dome, in the vicinity of the town of Fannett, contain only saline water even at very shallow depths. Because the area is topographically higher than the surrounding area, these sands should contain fresh water. The presence of saline water is probably a result of deeper artesian saline water flowing upward around the periphery of the dome and discharging into the shallower sands. Before well development, surface springs or seeps probably discharged some of this water.

DISPOSAL OF OIL-FIELD BRINES AND OTHER CONTAMINANTS

According to a 1961 salt-water inventory, about 60.4 million barrels of oil-field brine was produced during 1961 in Chambers and Jefferson Counties. Of this quantity, 66 percent was returned to saline water-bearing formations by injection wells, 26 percent was released to surface-water courses, 7.5 percent was

disposed of in open pits, and 0.5 percent was disposed of by miscellaneous or "unknown" processes (Texas Water Commission and Texas Water Pollution Control Board, 1963, p. 46-86 and 258-287).

The method of disposal of least danger to fresh ground-water supplies is injection through properly constructed wells; probably the most dangerous method is disposal of the brine in open pits. In Chambers and Jefferson Counties, the average annual precipitation is 54 inches and the average annual gross lake-surface evaporation is 47 inches. To be effective in brine disposal, the open pit must be constructed in sandy soil. Such construction allows the brine to seep into the ground, thereby contaminating the ground water. Most open pits are constructed in clay soil and act as holding or storage ponds. They may fill and overflow to the nearest stream or area of sandy soil.

Although contamination of ground water has probably occurred in places from the disposal of oil-field brines, no known large-scale damage to the ground-water supplies of Chambers and Jefferson Counties has occurred. Dead trees and other vegetation noted in the vicinity of old brine pits were probably killed by brine that overflowed or seeped out of the pits. In most of these areas, injection wells have replaced pits. Many injection wells have been drilled since the 1961 saltwater inventory, and the ratio of pit to injection-well disposal is constantly improving.

Large quantities of saline waste water are produced by industry in the vicinity of salt domes and large quantities of waste water are released in these and in other industrial areas. Much of this water comes from sulfur mining and from the construction of storage chambers in salt domes. Facilities to gather and hold the waste water exist at most domes. At some locations this water is injected back into the subsurface, but at most locations ditches carry this water to large holding ponds or lakes from which the water is released to the surface-water courses of the area. Controlled releases from these lakes are made so as to minimize the effect on natural waters.

Contamination of the shallow ground water probably takes place in the vicinity of many of the gathering, holding, and release systems that are excavated in the surface formations, Those in clay probably do not need lining, but those systems in sandy soil are probably contributing inferior quality water to an already limited source of fresh ground water.

Most towns and industries dispose of their effluent in the tidal portion of the streams or into the bays, which already contain saline water. The most harmful effect of this practice is that under certain conditions this effluent kills fish and wildlife, and the effluent often imparts noxious odors and colors to the streams and bays.

PROTECTION OF WATER QUALITY IN OIL-FIELD DRILLING OPERATIONS

The Railroad Commission of Texas requires that contractors drilling oil and gas wells use casing and cement to protect fresh-water strata from contamination. For more than the past decade, the Railroad Commission has received recommendations from the Texas Water Development Board and from its predecessors, the Texas Water Commission and the Texas Board of Water Engineers, concerning the depths to which the water should be protected.

Where oil or gas fields are established, the recommended depths are incorporated in some of the field rules. Figure 15 shows the amount of surface casing required by the Oil and Gas Division of the Railroad Commission of Texas and the depth of slightly saline water in those fields in Chambers and Jefferson Counties having surface-casing requirements. Figure 16 is a map showing the approximate altitude of the base of slightly saline water.

AVAILABILITY OF GROUND WATER

Evangeline Aquifer

The Evangeline aquifer contains fresh water only in parts of western Chambers County and northern Jefferson County. Assuming a porosity of 30 percent, about 2,600,000 acre-feet of fresh water is stored in western Chambers County and about 800,000 acre-feet

of fresh water is stored in northern Jefferson County; however, only a small part of this water could be recovered because of specific retention of much of this water and because of encroachment of nearby salt water. The fresh water extends to depths greater than 1,400 feet below sea level in western Chambers County and to depths of more than 1,000 feet below sea level in northern Jefferson County. Areas where fresh water occurs in the Evangeline aquifer underlie less than 10 percent of the combined areas of these counties. The maximum thicknesses of fresh-water sands is greater than 400 feet in Chambers County and greater than 200 feet in Jefferson County (Figure 17). Several large capacity industrial wells are completed in the Evangeline on the southwest flank of the Barbers Hill Dome. One irrigation well, in the Houston Point area of Chambers County, is completed in the Evangeline and lower unit of the Chicot.

Wells yielding 1,000-3,000 gpm could be constructed in northwestern Chambers County where sands in the Evangeline contain fresh water to depths approaching 1,500 feet below sea level.

Some sands of the Evangeline aquifer contain fresh water in parts of the Houston Point area. These sands and the Chicot sands above them are currently being tested and evaluated by the industries that are establishing new plants. Limited uses for sanitary purposes and boiler-feed water are planned. Wells yielding 100-1,000 gpm from the Evangeline aquifer could be developed in this area. The proximity of slightly saline water in the same beds in this area will probably preclude any large scale development of this water as a dependable source.

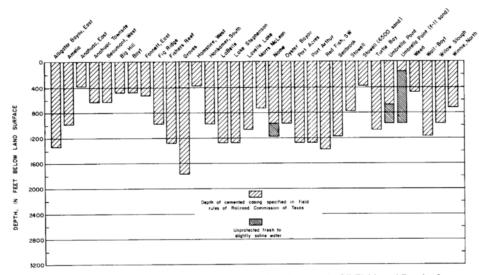


Figure 15.—Comparison Between Surface-Casing Requirements in Oil Fields and Depth of Base of Sands Containing Fresh to Slightly Saline Water

Chicot Aquifer

Lower Unit

The approximate base and thickness of the freshwater sands in the lower unit of the Chicot aquifer are shown on Figure 18. The lower unit of the Chicot contains fresh water in the Houston Point, Mont Belvieu, and Galveston Bay areas of Chambers County and in a small area along the eastern boundary of Jefferson County. The deepest occurrence of fresh water is in western Chambers County where fresh water extends to depths of more than 800 feet below sea level. Here the net thickness of sands containing fresh water is greater than 100 feet. In Jefferson County the maximum sand thickness is less than 50 feet. Fresh water in this aquifer underlies about a third of Chambers County and less than 5 percent of Jefferson County.

In the Houston Point and Mont Belvieu areas of northwestern Chambers County, the only place in which the lower unit of the Chicot has not been affected by saline water from Barbers Hill Dome is northwest of the dome. In this small area, all of the water in the aquifer is fresh. Large capacity wells that would produce fresh water could be constructed here.

The town of Mcnt Belvieu is using two publicsupply wells (DH-64-09-301 and DH-64-09-302) near the saline water. Water from the public-supply wells will probably become more saline as pumping continues.

Assuming a porosity of 30 percent, almost 4,000,000 acre-feet of fresh water is stored in the lower unit of the Chicot aquifer in Chambers County, 2,900,000 acre-feet of which underlies 150 square miles of Galveston Bay. Only a small part of these quantities could be pumped, however, because of specific retention of much of the water and because of encroachment of nearby salt water.

About 150,000 acre-feet of fresh water is stored in the lower unit of the Chicot aquifer in Jefferson County. The wells tapping this fresh-water supply are all near the interface of the fresh water with the slightly saline water. Extensive development of additional fresh water will cause saline water to move into the wells. Many of the wells developed in this aquifer in eastern Jefferson County already produce slightly or moderately saline water which is used by industry for cooling and fire protection. Wells that produce up to 3,000 gpm have been developed in the aquifer, and additional wells of this capacity can be constructed.

Generally, more than 100 feet of saturated sand containing slightly to moderately saline water is present in most places, and in a large area along the southern boundaries of the counties, massive beds in the aquifer total more than 500 feet in thickness. Large (tens of mgd) sustained withdrawals of moderately saline water

could be made in most areas of the two counties without excessive drawdown in water levels.

Upper Unit

The most widespread aquifer containing fresh water in Chambers and Jefferson Counties is the upper unit of the Chicot. Generally, it contains fresh water in and beyond the same areas as the lower unit of the Chicot and the Evangeline aquifers. However, in over 50 percent of Chambers and Jefferson Counties, only small supplies can be developed in this aquifer. Individual sand beds range in thickness from several feet to about 50 feet. Wells produce or have produced up to 1,000 gpm of fresh water from this aquifer in the Houston Point area of eastern Chambers County, at Anahuac, and in a fairly large area centered at Winnie. Additional freshwater wells can be constructed in this aquifer in these areas of Chambers County and in extreme northern Jefferson County without an immediate threat of water-quality deterioration.

Throughout much of Chambers and Jefferson Counties water of poorer quality underlies or occurs at short distances from many of the producing wells. With continued pumpage, some of these wells probably will produce poorer quality water.

The approximate altitude of the base of fresh water in the upper unit of the Chicot aquifer is shown in Figure 19. The deepest occurrence of fresh water is in the northernmost part of Jefferson County where the base is greater than 200 feet below sea level. The base of fresh water becomes more shallow to the south and is only a few feet below sea level in the central and southern parts of Chambers and Jefferson Counties.

QUATERNARY GEOLOGY

Ву

Saul Aronow

Geologic field studies in southeastern Texas that contributed to the preparation of this report were supported by grants from the National Science Foundation, Lamar Tech Research Center, and Sigma Xi.

Most of the systematic field work was done as part of the Geologic Atlas of Texas project of the Bureau of Economic Geology of the University of Texas. The geologic map of Chambers and Jefferson Counties (Figure 20) was adapted from preliminary copies of the Houston and Beaumont sheets of the Geologic Atlas (Bureau of Economic Geology, 1968a and 1968b).

The Soil Conservation Service of the U.S. Department of Agriculture provided technical assistance in the

field and provided copies of published and unpublished maps of soil surveys in Chambers and Jefferson Counties.

Marcus E. Milling, Marcus W. Walsh, Ben Wicker, and George Zahar, geology students at Lamar Tech, aided the author in mapping geomorphic features, in the preparation of illustrations, and in the determination of stream gradients.

General Stratigraphy and Structure

The geologic units in Chambers and Jefferson Counties (Figure 20) crop out in belts that are nearly parallel to the shoreline of the Gulf of Mexico. The beds dip toward the Gulf, with the older beds dipping at steeper angles than the younger beds. Most formations thicken downdip. The regional (gulfward) dip is interrupted by uplifts associated with salt domes and by arcuate belts of normal faults that are generally downthrown to the Gulf.

The oldest unit that crops out in Chambers and Jefferson Counties is the Beaumont Clay of Pleistocene age (Bernard, LeBlanc, and Major, 1962). The alluvial terrace deposits along the modern floodplains of the Trinity and Neches Rivers, mapped by Bernard (1950) as the "Deweyville beds", are probably of late Pleistocene and Holocene age. The youngest sediments are floodplain, deltaic, coastal marsh, mud flat, and beach (chenier) deposits of Holocene age.

Beaumont Clay

The Beaumont Clay crops out across most of Chambers and Jefferson Counties (Figure 20). The formation was described by Hayes and Kennedy (1903, p. 27-29), from exposures and from samples from wells in the vicinity of Beaumont, as a "series of yellow, gray, blue, brown, and black clays with black sands" overlying the "Columbia sands."

No definite type section has been described, and probably no complete section can be described from the outcrops alone. A type well or a combination type well and surface section can be established only when some unequivocal means of determining the base of the formation can be agreed upon. Bernard (1950) mapped the Beaumont in Texas as its presumed equivalent in Louisiana, the Prairie Formation; Doering (1956) mapped it as the Oberlin and Eunice Formations; Price (1947) mapped it as the Montgomery and Prairie Formations; and Bernard and LeBlanc (1965) reverted to the original name, Beaumont Clay, as used on the geologic map of Texas (Darton and others, 1937).

Two mappable facies of the Beaumont Clay occur in Chambers and Jefferson Counties: (1) a clayey facies composed of alluvial, deltaic, coastal marsh, and

lagoonal deposits of clay, silty clay, and sandy clay; and (2) a sandy facies composed of barrier island and beach deposits of very fine to fine sand, which are of local importance as sources of small quantities of fresh ground water.

The clayey facies of the Beaumont composes almost all of the exposed Pleistocene sediments in Chambers and Jefferson Counties. For descriptions of these facies see Crout and others (1965), McEwen (1963, p. 63-64), Kunze and others (1963), and Graf (1966, p. 6, and Figure 8).

The sandy facies of the Beaumont Clay compose a very small percentage of the exposed Pleistocene sediments in Chambers and Jefferson Counties. The material is mostly very fine to fine, well-sorted sand of the barrier island and beach deposits (mapped separately on Figure 20). Grain-size determinations by mechanical analyses and heavy-mineral data are given in Graf (1966).

Deltaic and Meander Belt Deposits

Barton (1930a, 1930b) concluded that the coastal area of southeastern Texas was deltaic plain deposited by Pleistocene streams. The main evidence for this interpretation was the meandering pattern of the sandier soils, found in many places on the crests of low "levee" ridges. Barton pointed out that most of the present drainage is between and is controlled by the old levee or distributary ridges.

The major difference between the views of Barton and those of the author is in the significance of the levee or distributary ridges. Barton believed that the meander belts were a relict group of passes with a "palmate" pattern, similar to that of the present-day Mississippi Delta. The deposits of the Pleistocene Trinity River would therefore represent a delta as large as or larger than the present Mississippi Delta. Barton concluded that the Pleistocene Trinity River had a greater discharge and load than at present because of higher precipitation and a diminution in the drainage basin since the Pleistocene. The author believes that this group of passes was actually a succession of meander belts that terminated in relatively small deltas, similar in size to the present day Trinity River Delta.

A map compiled from the latest soil survey of Jefferson County (Crout and others, 1965) that shows the meander belts defined by mapping the soils that are related to fluviatile deposits is shown as Figure 21.

As shown in Figure 22, there are four well-preserved, more or less continuous meander belts and one less definite belt in Chambers and Jefferson Counties. In order of decreasing age, they are: (1) the Neches Ridge System, which roughly parallels the Neches River in the extreme eastern part of Jefferson

County—the relict meanders in this system are fragmentary and obscure, but the soils are similar to the soils found in the other systems;(2) the Barbers Hill System, between the Trinity River and Cedar Bayou; (3) the Sea Breeze System, in eastern Chambers County; (4) the Big Hill Ridge System; and (5) the China Ridge System, which is the best preserved and has the greatest continuity.

The system of straight stretches of relict stream channels to the northwest and southeast of the Smith Point and Pine Island barriers may be the remains of a stream that was not a tributary to the Pleistocene Trinity River but flowed directly into the Gulf. Figure 20 shows a number of anomalous meanders that cannot be defined as a coherent system.

The bluffs along Trinity Bay and along the valleys of the Trinity and Neches Rivers are the result of stream cutting during a glacial lowering of sea level. Wave erosion of the areas bordering Lake Anahuac and Trinity Bay has maintained the steepness of the bluffs in those areas. East of the Trinity River, the contact of the Deweyville deposits with the Beaumont Clay is marked by low scarps less than 10 feet in height.

The contact of the Beaumont Clay with the marsh and fluviatile deposits of Holocene age between Smith Point in Chambers County and Sabine Lake in Jefferson County has a digitate pattern, and only a few of the recesses are occupied by larger streams. Most of the salients of the Beaumont Clay are levee or distributary ridges similar to those of the Trinity River Delta, and the center lines of some of them are water-filled or marshy depressions. Those that do not have axial depressions can be identified by their sandy soils, by their terminal position in relation to the meander system, and by their areal pattern. The margins of most of these small deltas, which are about 5 feet above sea level, slope gently under the marsh deposits. The termination of the Neches Ridge System does not have a clearly digitate pattern, but does have approximately the same elevation as the other terminations.

The average slope of the surface of the Beaumont Clay east of the Trinity River in Chambers County is about 1 foot per mile. West of the Trinity River, the slope is about 1.5 feet per mile. The gradients of the two best preserved meander belts (not the old stream gradients) are: Big Hill Ridge System, 1.64 feet per mile; and China Ridge System, 0.92 foot per mile. The reconstructed stream gradients are: Big Hill Ridge System, 0.75 foot per mile; and China Ridge System, 0.49 foot per mile.

McEwen (1963), in his study of the most recent delta of the Trinity River, found that the whole delta was only about 15 feet thick. On this basis, a local thickness for the Beaumont Clay of less than 100 feet can easily be conjectured. Should a widespread and easily identifiable lithologic change be found that has

some reasonable relationship to the subsurface projection of the surface of the Montgomery Formation, then perhaps the base of the Beaumont can be defined.

Barrier Island and Beach Deposits

The barrier island and beach deposits (Figure 20) were first described by W. A. Price (1933, 1947), and named for the occurrence at Ingleside, near Aransas Pass, Texas. As mapped by Price, the Ingleside System is a series of discontinuous features extending along most of the Gulf Coast of Texas. In Chambers and Jefferson Counties, the barrier island and beach deposits, which are composed of very fine to fine sand, may be divided into three sections-one in Chambers County and two in Jefferson County (see areas marked Qbb on Figure 20). The section in Chambers County consists mainly of three elongated parts, each less than 1 mile wide, extending from Smith Point northeastwardly for a distance of about 20 miles, the part from Smith Point to Lake Stephenson is a ridge that rises about 10 feet above the adjacent marshland (altitude about 12 feet). The ridge contains a number of small, nearly circular lakes. The remainder of this section is more easily identified on soil maps and aerial photographs. The sections in Jefferson County are west of Fannett and in the western part of the city of Beaumont. The one west of Fannett is an irregularly shaped area about 4 miles in width that is essentially a series of abandoned beaches of "cheniers" similar to those near Sabine Pass. Altitudes range from about 15 to 25 feet. This section is forested and is locally called "Lawhorn Woods." The section in the western part of the city of Beaumont is about 3 miles long and about 1 mile in width. The altitude is about 20 feet, but because of urban development, this section is difficult to identify.

Mounds and Depressions

Widespread surface features of the Beaumont Clay, and of the Deweyville deposits, are the "pimple mounds." These circular to elliptical mounds are about 15 to about 50 feet in diameter and 1 to 4 feet in height. They are almost exclusively limited to the sandier and siltier soils that underlie the relict meander belts and the barrier island and beach system. They are largely absent from the gentle swales or relict backswamp areas between meander belts and from some, but not all, of the relict lagoonal areas landward of the old barriers. Pimple mounds are best developed and most abundant on the old barriers.

The origin of pimple mounds is not clearly understood, and they have been considered the result of both organic and inorganic processes. Mounds of this type are not restricted to the Gulf Coast, and similar features elsewhere are sometimes referred to as mima mounds. Discussion of these features goes back to the 1870's; reviews of the literature and references can be

found in Melton (1954), Holland and others (1952), and in Bernard and Leblanc (1965, p. 174-176).

The hog wallows or "gilgai microrelief" (Crout and others, 1965, p. 6; Mowery and others, 1960, p. 11, 33), are a minor but locally conspicuous kind of surface feature. These are areas of uneven or "wavy" ground consisting of very low mounds or microknolls (less than 2 feet in diameter and less than 8 inches in height) and intervening depressions. They usually become apparent after a heavy rain when the depressions impede surface drainage. In Chambers and Jefferson Counties, hog wallows are restricted to the clayier soils. They are thought to result from the unequal absorption of water or dehydration by certain clay minerals.

Geologic Age

The Beaumont Clay is at least 30,000 years old as determined by radiocarbon dating. McFarlan (1961, p. 133) reported that samples from the Prairie Formation of Louisiana (correlative with the Beaumont Clay) were "dead" and older than 30,000 years. Oyster shells collected by the author from the relict lagoonal area north of Lake Charles, Louisiana, were likewise "dead" and were older than 40,000 years according to Dr. E. L. Martin, Shell Development Co., Exploration and Production Research Division, Houston, Texas. The shell material collected near Winnie by Professor W. H. Matthews was also "dead" and older than 37,000 years according to the Humble Oil and Refining Company (now Esso Production Research), Houston, Texas.

Deweyville Deposits of Bernard (1950)

The Deweyville deposits in Chambers and Jefferson Counties are found along the Trinity and Neches Rivers and are intermediate between the Beaumont Clay and the modern flood plain deposits of the two rivers.

These deposits were first mapped and described by H. A. Bernard (1950), in an unpublished doctoral dissertation. They were named for the community of Deweyville, in Newton County, Texas, about 12 miles north of Orange. Texas, where the deposits form a terrace flanking the Holocene flood plain of the Sabine River. On the Beaumont and Houston Sheets of the Geologic Atlas of Texas (Bureau of Economic Geology, 1968a and 1968b), the Deweyville deposits are identified as the Deweyville Formation.

Along the Neches River in Jefferson County, the Deweyville deposits form a single-level terrace north of the city of Beaumont. The deposits range from silty clay to very fine sand in some places and from very fine sand to coarse sand in others. The top of these deposits, which are at least 30 feet thick, is about 20 feet above

In Chambers County, the Deweyville deposits are on the eastern side of the Trinity River where they form at least three terrace levels ranging in altitude from 15 to 25 feet. As seen in road cuts, the deposits are clayey silts and silty sands. In several sand pits, the clayey silts and silty sands are underlain by very fine to coarse sand. Incomplete soil maps in the office of the U.S. Soil Conservation Service in Anahuac show that the higher terraces are underlain in many places by soils that are characteristic of the Beaumont Clay, and therefore may be considerably older than the deposits along the Neches River where a sequence of terraces is not present.

The age of the Deweyville deposits has been determined by radiocarbon methods for several localities outside of Chambers and Jefferson Counties. Aronow (1967) reported on samples from deposits along the Trinity, San Jacinto, and Sabine Rivers; and B. H. Slaughter (1965) reported on a sample, which the author interprets to be Deweyville, from deposits along the Trinity River. The dates of these samples range from 13,250 to 25,700 years. Bernard and Leblanc (1965, p. 149) give dates ranging from 17,000 to 30,000 years, but no localities are identified in their paper.

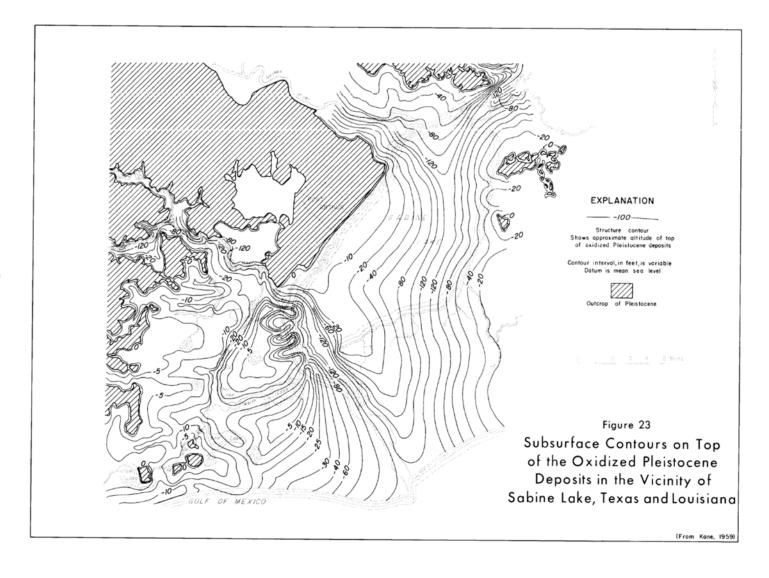
Holocene Deposits

Alluvial and Deltaic Deposits

The principal alluvial deposits of Holocene age are along the Neches River in Jefferson County, along the Trinity River in Chambers County, and in an extensive area along the coast. The principal deltaic deposits of Holocene age are at the mouth of the Trinity River. A map by Kane (1959) showing subsurface contours on top of the oxidized Pleistocene deposits (base of the Holocene) in the vicinity of Sabine Lake is included on Figure 23.

The geomorphology of the floodplains and deltas of the Holocene Trinity River has been worked out in some detail by Aten (1966a and 1966b), who distinguishes a sequence of five delta terminations. The sediments and the three-dimensional geometry of the most recent delta have been studied in detail by McEwen (1963), who divides the sediments of the delta into nine facies or genetic groups.

The modern delta of the Trinity began to form within the past 1,000 years. McEwen (1963, p. 93) reports that the two oldest radiocarbon dates of articulated *Rangia flexuosa* shells found in cores taken near the bottom of delta-front churned sands in the northwest part of the delta are 810 years and 750 years



Coastal Marsh, Mudflat, and Beach (Chenier) Deposits

The coastal marsh, mud flat, and beach (chenier) deposits along the southern margins of Chambers and Jefferson Counties are the most extensive of the Holocene deposits. The coastal marsh sediments underlie the low plains areas separated from the Gulf by the most recent beaches and include the deposits between relict beaches in the Sabine Pass area of Jefferson County (See Bernard and Leblanc, 1965, Figure 5). The mud flats are the areas of fine-grained sediments gulfward of the most recent beaches.

The surface features in the Sabine Pass area of Texas consist of low beach ridges and intervening relict mud flat or coastal marsh deposits. As can be seen on Figure 20, these arcuate beach ridges or cheniers, convex towards the present shoreline, merge to the southwest into a single beach along the present coast. The ridges, which are 3 to 8 feet in height and as much as 10 miles long, consist of very fine to fine sand with a highly variable shell content. The sand is similar in size to the Holocene beach sands of Galveston Island and Bolivar Peninsula to the west and to the cheniers in Louisiana to the east. (See Hsu, 1960, p. 381-384; Garner, 1967, p. 49-52, 57).

A number of wells, all less than 15 feet deep, have been developed in the beach and associated shell deposits.

Arcuate, fan-like arrangement of the beach ridges on the Texas side of Sabine Pass is more or less duplicated on the Louisiana side of the Pass. This arrangement undoubtedly indicates the gradual closing of the mouth of Sabine Lake by constriction of its southern connection with the Gulf. Originally, Sabine Lake must have been an open estuary of the Gulf. Kane (1959) in his study of the micro-fauna and sediments of Sabine Lake concludes that the micro-fauna, especially the foraminifers, found in the sediments beneath the lake "are similar to those of the present Gulf, indicating greater circulation of saline waters from the Gulf of Mexico before the south end of Sabine Lake was restricted".

Geologic History

The geologic history of the surface formations of Chambers and Jefferson Counties can be tied into the framework of the Pleistocene and Holocene history of the western Gulf Coast region as worked out by H. N. Fisk and his many associates. Later work and areal extensions of Fisk's concepts have been recently and excellently summarized in Bernard and LeBlanc (1965) which contains references to Fisk's many papers.

Fisk believed that the Pleistocene formations of Louisiana and Texas were all deposited as coast-wise

terraces between the major stages of continental glaciations, with each successive Pleistocene formation being tilted gulfward. The amount of tilt was cumulative, so that the oldest formation has a considerably greater dip than the youngest.

The Montgomery Formation (with a regional slope of more than twice that of the Beaumont Clay) was deposited during the Sangamon Interglaciation; the Beaumont Clay, or Prairie Formation, was deposited during post-Sangamonian time. (See Fisk and McFarlan, 1955). The glacial stages were times of low sea level when the streams of the Gulf Coast entrenched their channels well below present-day sea level. Estimates of the lowering of sea level during the last glacial stage range from about 300 to 450 feet. The Trinity and Neches Rivers, during the last lowering of sea level, flowed over a 100-mile stretch of the then exposed continental shelf before discharging into the Gulf. (See maps in: Fisk and McFarlan, 1955, figure 4; Curray, 1965, figure 19a; Kane, 1959, figure 2). Kane's map of the oxidized zone at the top of the Beaumont Clay showed that the entrenched valleys of the Neches and Sabine Rivers joined under the present site of Sabine Lake (Figure 23). The sediments deposited since the beginning of the Holocene are those that lie above this marker horizon, which extends beneath the land areas and continues as an unconformity beneath the continental shelf. (See Bernard and LeBlanc, 1965, p. 150, 177-179; Curray, 1965, p. 733).

The time of the lowest sea level during the mid-Wisconsin has been estimated as more than 25,000 years ago by Bernard and LeBlanc (1965, p. 149) and about 18,000 years ago by Curray (1965, p. 723-724).

Sea level rose to its present level perhaps 3,000 to 5,000 years ago and has remained at about the same level. The various coastal features of Holocene age, seaward of the outcrop of the Beaumont Clay, are all less than 5,000 years old. Trinity Bay and Sabine Lake are essentially drowned valleys of the entrenched Pleistocene Trinity and Neches Rivers.

A few recent concepts and reformulations of the glacial stratigraphy and history of the midwestern United States have pointed up some areas where Fisk's theories seem to need revision; see Flint (1963), Frye and Willman (1960), Frye, Willman, and Black (1965), Frye and Leonard (1965), Curray (1965), Frye and Leonard (1965), Bernard and LeBlanc (1965), Durham (1965), Aten (1966a, 1966b), and Aronow (1967).

The Pleistocene history of the western Gulf Coast in general and of Chambers and Jefferson Counties in particular is far from worked out in detail, and much work remains to be done.

CONCLUSIONS AND RECOMMENDATIONS

Only small supplies of fresh ground water exist in the aquifers in Chambers and Jefferson Counties. Most of the fresh water used is surface water from the Trinity and Neches Rivers. Fifty-two percent of the ground water used is imported from neighboring counties. Large quantities of fresh ground water are available in adjoining counties and any large-scale demand for fresh ground water will likely be met by additional importation. Except for Beaumont's planned expansion of its well field in Hardin County, most future water needs will probably be met by surface-water supplies. Additional small fresh water supplies can be developed in Chambers and Jefferson Counties, but this development should be preceded by a careful program of testing and evaluation.

To fully utilize available ground water, the observation-well program in Chambers and Jefferson Counties to obtain data on both quality of water and water levels should not only be continued, but expanded and combined with the programs in adjacent counties. At present, the observation-well program in Chambers and Jefferson Counties covers only parts of the area. The expansion of this program should consider the planned increase of pumpage in Hardin County as well as anticipated increases in other counties. New wells should be continually inventoried, and aquifer tests should be made on the new wells to obtain additional information on the hydraulic properties of the aquifers. Collection of water samples should be expanded to monitor salt movement in all areas. Detailed observation of water levels and water quality in the vicinity of the salt domes, particularly in the vicinity of Mont Belvieu, is needed in

order to more precisely define and predict the movement of water in these areas of salinization.

Subsidence, as related to ground-water production, is, and will likely remain, a minor problem because additional development will probably be limited. Water levels will probably continue to be lowered by pumping in adjacent counties. However, data derived from measurements of subsidence when used with geologic and hydrologic data are useful in determining maximum water availability. This type of data has been used in the construction of analog models in this area. Also, knowledge of amount and rate of subsidence is important in planning surface drainage and water transfer facilities. Thus, an expanded program for measuring subsidence is needed in Chambers and Jefferson Counties. Further delay in starting such a program may prevent accurate determination of total subsidence and rates of subsidence. An enlarged network of bench marks should be established and leveled periodically. This program should be in conjunction with the program for the collection of water-level and pumpage records, so that correlations of cause and effect of subsidence can be made in the future.

Electrical-analog models are useful in the evaluation of aquifers. Such a model has been completed for the aquifers of the Houston district (Wood and Gabrysch, 1965). A preliminary model of the Chicot and Evangeline aquifers in southeast Texas and southwest Louisiana, including Chambers and Jefferson Counties, has been constructed. The program recommended above will provide data that could be used to improve the models and aid in the proper planning and development of the ground-water resources of Chambers and Jefferson Counties.

REFERENCES CITED

- American Society for Testing Materials, 1959, Manual on industrial water and industrial waste water: Am. Soc. for Testing Materials Spec. Tech. Pub. 148-D, 2nd., 653 p, [1960].
- Anders, R. B., McAdoo, G. D., and Alexander, W. H., Jr., 1968, Ground-water resources of Liberty County, Texas: Texas Water Devel. Board Rept. 72, 140 p.
- Aronow, Saul, 1967, Place of the Deweyville Formation in the Western Gulf Coast Recent-Pleistocene sequence: Program 1967 Southeastern Sec. Geol. Soc. America Ann. Mtg., Tallahassee, Florida, p. 15-16.
- Aten, L. E., 1966a, Late Quaternary alluvial history of the Lower Trinity River, Texas, a preliminary report, in Shafer, H. J., An archeological survey of Wallisville Reservoir, Chambers County, Texas: Texas Archeol. Salvage Proj. Survey Rept. no. 2, p. 39-43.
- —____1966b, Late quaternary surface geology of the Lower Trinity River area, Southeastern Texas: Univ. of Houston, Dept. Geology, unpublished rept., 29p.
- Baker, E. T., Jr.. 1964, Geology and ground-water resources of Hardin County, Texas: Texas Water Comm. Bull. 6406, 179 p.
- Barton, D. C., 1930a, Deltaic Coastal Plain of southeastern Texas: Geol. Soc. America Bull., v. 41, no. 3, p. 359-382.
- _____1930b, Surface geology of coastal southeast Texas: Am. Assoc. Petroleum Geologists Bull., v. 14, no. 10, p. 1301-1320.
- Bernard, H. A., 1950, Quaternary geology of southeast Texas: Louisiana State Univ., doctoral dissertation, 165 p.
- Bernard, H. A., and LeBlanc, R. J., 1965, Resume of the Quaternary geology of the northwestern Gulf of Mexico Province, in Wright, H. E., and Frey, D. G., eds., The Quaternary of the United States: Princeton, N. J., Princeton Univ. Press, p. 137-185.
- Bernard, H. A., LeBlanc, R. J., and Major, C. F., 1962, Recent and Pleistocene geology of southeast Texas, in Geology of the Gulf Coast and Central Texas and guidebook of excursions: Geol. Soc. America, 1962 Ann. Mtg., Houston, Texas, Houston Geol. Soc., p. 175-224.
- Bureau of Economic Geology, 1968a, Geologic Atlas of Texas, Beaumont Sheet: Univ. Texas at Austin, Bur. Econ. Geology map.
- ——1968b, Geologic Atlas of Texas, Houston Sheet: Univ. Texas at Austin, Bur. Econ. Geology map.

- Cooper, H. H., Jr., and Jacob, C. E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: Am. Geophys. Union Trans., v. 27, p. 526-534.
- Crout, J. D., Symmank, D. G., and Peterson, G. A., 1965, Soil survey of Jefferson County, Texas: U.S. Dept. Agr. Ser. 1960, no. 21.
- Curray, J. R., 1965, Late Quaternary history, continental shelves of the United States, in Wright, H. E., and Frey, D. G., eds., The Quaternary of the United States: Princeton, N. J., Princeton Univ. Press, p. 723-735.
- Darton, N. H., Stephenson, L. W., and Gardner, Julia, 1937, Geologic map of Texas: U.S. Geol. Survey map.
- Deussen, Alexander, 1914, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U.S. Geol. Survey Water-Supply Paper 335, 365 p.
- Doering, John, 1956, Review of Quaternary surface formations of Gulf Coast Region: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 8, p. 1816-1862.
- Doyel, W. W., 1956, Basic data and summary of ground-water resources of Chambers County, Texas: Texas Water Comm. Bull. 5605, 77 p.
- Durham, C. O., 1965, Stream activity in the Central Gulf Coast area during the Wisconsin Glacial (abs): Geol. Soc. America Spec. Paper 82, p. 298.
- Fenneman, N. M., 1938, Physiography of eastern United States: New York, McGraw-Hill Book Co., Inc., 714 p.
- Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536-E, 173 p.
- Fisk, H. N., 1940, Geology of Avoyelles and Rapides Parishes: Louisiana Dept. Conserv. Bull. 18, 240 p.
- Fisk, H. N., and McFarlan, Edward, Jr., 1955, Late Quaternary deltaic deposits of the Mississippi River *in* Poldervaart, Arie, ed., Crust of the earth: Geol. Soc. America Spec. Paper 62, p. 279-302.
- Flint, R. F., 1963, Status of the Pleistocene Wisconsin stage in Central North America: Science, v. 139, no. 3553, p. 402-404.
- Frye, J. C. and Leonard, A. B., 1953, Definition of time line separating a Glacial and Interglacial Age in the

- Pleistocene: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 11, p. 2581-2586.
- Frye, J. C., and Leonard, A. B., 1965, Quaternary of the Southern Great Plains in Wright, H. E., and Frey, D. G., eds: The Quaternary of the United States: Princeton, N. J., Princeton Univ. Press, p. 203-216.
- Frye, J. C., and Willman, H. B., 1960; Classification of the Wisconsinan Stage in the Lake Michigan Glacial Lobe: Illinois Geol. Surv. Circ. 285, 16 p.
- Frye, J. C., Willman, H. B., Black, R. F., 1965, Outline of glacial geology of Illinois and Wisconsin, in Wright, H. E., and Frey, D. G., eds., The Quaternary of the United States: Princeton, N. J., Princeton Univ. Press, p. 43-61.
- Gabrysch, R. K., 1967, Development of ground-water in the Houston district, Texas, 1961-65: Texas Water Devel. Board Rept. 63.
- Garner, L. E., 1967, Sand resources of Texas Gulf Coast: Univ. Texas at Austin, Bur. Econ. Geology Rept. Inv. 60, 85 p.
- Graf, C. H., 1966, The Late Pleistocene Ingleside Barrier trend: Rice Univ. masters thesis, 83 p.
- Hackett, O. M., 1962, Ground-water levels in the United States, 1956-59, south central states: U. S. Geol. Survey Water-Supply Paper 1549, 192 p.
- Hanna, M. A., 1958, Salt dome structures: Gulf Oil Company Petroleum Indoctrination Course, 45 p.
- Harder, A. H., 1960, Geology and ground-water resources of Calcasieu Parish, Louisiana: U.S. Geol. Survey Water-Supply Paper 1488, 102 p.
- Hawkins, M. E., and Jirik, C. J., 1966, Salt domes in Texas, Mississippi, Alabama, and offshore tidelands, a survey: U.S. Bur. Mines, I.C. 8313, 78p.
- Hayes, C. W., and Kennedy, William, 1903, Oil fields of the Texas-Louisiana Gulf Coastal Plain: U.S. Geol. Survey Bull. 212, 174 p.
- Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p.
- Holland, W. C., Hough, L. W., and Murray, G. E., 1952, Geology of Beauregard and Allen Parishes: Louisiana Dept. of Conserv. Bull. no. 27, 224 p.
- Hsu, J. H., 1960, Texture and mineralogy of the Recent Sands of the Gulf Coast: Jour. Sed. Petrology, v. 30, no. 3, p. 380-403.
- Kane, H. E., 1959, Late Quaternary geology of Sabine

- Lake and vicinity, Texas and Louisiana: Gulf Coast Assoc. Geol. Soc. Trans., v. 9, p. 225-235.
- Kane, J. W., 1967, Monthly reservoir evaporation rates for Texas, 1940 through 1965: Texas Water Devel. Board Rept. 64, 111 p.
- Kennedy, W., 1892, A section from Terrell, Kaufman Co., to Sabine Pass on the Gulf of Mexico: Texas Geol. Survey 3d Ann. Rept., p. 45 and 62.
- Kunze, G. W., Oakes, Harvey, and Bloodworth, M. E., 1963, Grumosols of the Coast Prairie of Texas: Soil Sci. Soc. America Proc., v. 27, no. 4, p. 412-421.
- Lang, J. W., Winslow, A. G., and White, W. N., 1950, Geology and ground-water resources of the Houston district, Texas: Texas Board Water Eng. Bull. 5001, 59 p.
- Livingston, Penn, and Cromack, G. H., 1942a, Records of wells, drillers' logs, water analyses, and maps showing locations of wells and test holes in Chambers County: Texas Board Water Eng. dupl. rept., 94 p.
- _____1942b, Well data, Jefferson County, Texas: Texas Board Water Eng. dupl. rept., 64 p.
- Maier, F. J., 1950, Fluoridation of public water supplies: Am. Water Works Assoc. Jour., v. 42, pt. 1, p. 1120-1132.
- McEwen, M. C., 1963, Sedimentary framework of the Trinity River Delta: Rice Univ. doctoral dissertation, 100 p.
- McFarlan, Edward, Jr., 1961, Radiocarbon dating of Late Quaternary deposits, south Louisiana: Geol. Soc. America Bull., v. 72, no. 1, p. 129-158.
- Melton, F. A., 1954, "Natural mounds" of northeastern Texas, southern Arkansas, and northern Louisiana: Hopper, v. 14, no. 7, p. 89-121.
- Moore, E. W., 1940, Progress report of the committee on quality tolerances of water for industrial uses: New England Water Works Assoc. Jour., v. 54, p. 263.
- Mowery, I. C., McKee, G. S., Matanze, Francisco, and Everett, Francis, 1960, Soil survey of Fort Bend County, Texas: U.S. Dept. Agr. Ser. 1955, no. 5.
- Price, W. A., 1933, Role of diastrophism in topography of Corpus Christi area, South Texas: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 8, p. 907-962.
- ——1947, Equilibrium of form and forces in tidal basins of coast of Texas and Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 9, p. 1619-1663.

- Rogers, J. E., and Calandro, A. J., 1965, Water resources of Vernon Parish, Louisiana: WaterResources Bull. no. 6, 104 p.
- Rose, N. A., 1943, Progress report on the ground-water resources of the Texas City area, Texas: U.S. Geol. Survey open-file rept. 45 p.
- Sandeen, W. M., 1968, Ground-water resources of San Jacinto County, Texas: Texas Water Devel. Board Rept. 80, 89 p.
- Scofield, C. S., 1936, The salinity of irrigation water: Smithsonian Inst. Ann. Rept., 1934-35, p. 275-287.
- Slaughter, B. H., 1965, Preliminary report on the Paleontology of the Livingston Reservoir Basin, Texas: Fondren Sci. Ser. 10.
- Tarver, G. R., 1968a, Ground-water resources of Tyler County, Texas: Texas Water Devel. Board Rept. 74, 91 p.
- _____1968b, Ground-water resources of Polk County, Texas: Texas Water Devel. Board Rept. 82, 109 p.
- Taylor, T. U., 1907, Underground waters of the Coastal Plain of Texas: U.S. Geol. Survey Water-Supply Paper 190, 73 p.
- Texas Water Commission and Texas Water Pollution Control Board, 1963, A statistical analysis of data on oil field brine production and disposal in Texas for the year 1961 from an inventory conducted by the Texas Railroad Commission: Railroad Commission Dist. 3, v. 2, 473 p.
- U.S. Public Health Service, 1962, Public Health Service drinking water standards: Public Health Service Pub. 956, 61 p.
- U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. of Agr. Handb. 60, 160 p.

- Walker, R. K., and Miears, R. J., 1957, The Coastal Prairies, in Soil, the Yearbook of Agriculture: Washington, D. C., Dept. of Agr., p. 531-534.
- Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials, with special reference to discharging well methods: U.S. Geol. Survey Water-Supply Paper 887, 192 p.
- Wesselman, J. B., 1965, Geology and ground-water resources of Orange County, Texas: Texas Water Comm. Bull. 6516, 112 p.
- —____1967, Ground-water resources of Jasper and Newton Counties, Texas: Texas Water Devel. Board Rept. 59, 167 p.
- Wilcox, L. V., 1955, Classification and use of irrigation waters: U.S. Dept. Agr. circ. 969, 19 p.
- Wilson, C. A., 1967, Ground-water resources of Austin and Waller Counties, Texas: Texas Water Devel. Board Rept. 68, 231 p.
- Winslow, A. G., and Kister, L. R., Jr., 1956, The saline water resources of Texas: U.S. Geol. Survey Water-Supply Paper 1365, 105 p.
- Winslow, A. G., and Wood, L. A., 1959, Relation of land subsidence to ground-water withdrawals in the upper Gulf Coast region, Texas: Mining Eng., p. 1030-1034.
- Wood, L. A., 1956, Availability of ground water in the Gulf Coast region of Texas: U.S. Geol. Survey open-file rept.
- Wood, L. A., and Gabrysch, R. K., 1965, Analog model study of ground water in the Houston district, Texas: Texas Water Comm. Bull. 6508, 103 p.
- Wood, L. A., Gabrysch, R. K., and Marvin, Richard, 1963, Reconnaissance investigation of the ground-water resources of the Gulf Coast region, Texas: Texas Water Comm. Bull. 6305, 114 p.

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Chambers Co	unty		Sand	13	554
Well DH-64-0			Shale and streaks of sand	34	588
			Sand	8	596
Owner: Gulf C Driller: Gulf C			Shale and sandy shale	51	647
Clay, surface	15	15	Sand	21	668
Gumbo	37	52	Shale	16	684
Sand	58	110	Sand and streaks of shale	40	722
Gumbo	18	128	Shale	5	727
Sand	21	149	Sand, coarse and streaks of shale	65	792
Gumbo	25	174	Shale and streaks of sand	16	808
Sand	22	196	Sand and streaks of shale	29	837
Gumbo	2	198	Shale	10	847
	× 201		Sand	13	860
Well DH-64-0			Shale	18	878
Owner: Chambers County Improvement Distric	t No. 1 Well 5		Shale and sand streaks	26	904
Driller: Layne-T		4	Sand, fine and shale streaks	101	1,005
Soil	4		Shale and sand streaks	63	1,068
Clay	111	115	Sand	5	1,073
Clay, sandy	45	160	Shale and sandy shale	53	1,126
Shale	30	190	Sand, fine white	13	1,139
Shale, sandy and shale	100	290	Shale, sandy and shale	15	1,154
Shale	108	398	Sand	13	1,167
Sand, fine gray	72	470	Shale and sandy shale	83	1,250
Shale	4	474			
Sand, coarse white	46	520	Well DH-64-0		
Shale	10	530	Owner: Diamond All Driller: Layne-1	cali Co. Well 4 Texas Co.	
Well DH-64-	09-302		Śurface soil	4	4
Owner: Chambers Coun	ty Water Control &		Clay	31	35
Improvement Distric Driller: Layne-	ct No. 1 Well 4 Texas Co.		Clay and lime breaks	41	76
Soil	4	4	Clay, sandy and few lime breaks	40	116
Clay	112	116	Clay, sticky	20	136
Shale, sandy	42	158	Clay, sandy	14	150
Shale	175	333	Clay	55	205
Sand and shale	8	341	Sand	18	223
Shale and streaks of sand	60	401	Clay	47	270
Sand, gray	74	475	Clay, sandy	27	297
Shale	3	478	Sand and clay breaks	40	337
Sand, coarse white	43	521	Shale, sandy	14	351
Shale	20	541	Sand, broken	19	370

Table 5.-Drillers' Logs of Wells in Chambers and Jefferson Counties-Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-09-305—Continued			Well DH-64-09	-306	
Shale	21	391	Owner: Warren Petr		
Shale, sandy	17	408	Driller: Layne-Te		
Shale	20	428	Surface soil	10	10
Sand	32	460	Clay	113	123
Sand, broken	25	485	Sand	15	138
Shale, sandy	24	509	Shale	172	310
Sand and shale breaks	19	528	Sand	60	370
Sand	37	565	Shale, sandy	70	440
Sand and shale streaks	29	594	Sand-cut good	90	530
Rock	1	595	Sand and layers of rock	5	535
Shale	28	623	Sandy coarse-cut good, little hard	43	578
Shale, sandy and sand	21	644	Shale	112	690
Shale	32	676	Sand, coarse with hard shale breaks	96	786
Shale, sandy	11	687	Sand-cut good	37	823
Sand	18	705	Sand, coarse with hard shale breaks	94	917
Shale	14	719	Shale-few sand breaks	81	998
Sand	51	770	Sand, fine	33	1,031
Sand and shale streaks	18	788	Sand, fine with shale breaks	54	1,085
Sand and few shale breaks	76	864	Sand	41	1,126
Shale	11	875	Shale and streaks of sand	25	1,151
Sand and shale, broken	30	905	Sand	30	1,181
Sand	23	928	Shale	9	1,190
Shale, sandy and shale breaks	25	953	Sand and streaks of shale	29	1,219
Shale	22	975	Shale	26	1,245
Shale, sandy	10	985	Sand	20	1,265
Sand and lime breaks	125	1,110	Shale and few sand breaks	21	1,286
Sand and shale breaks	124	1,234	Sand	27	1,313
Shale	10	1,244	Shale	40	1,353
Sand	37	1,281	Sand and few shale breaks	103	1,456
Shale	10	1,291	Shale	11	1,467
Sand	10	1,301	Sand, coarse, cut good	22	1,489
Shale	37	1,338	Shale	8	1,497
Sand	19	1,357	Sand, coarse and shale breaks	30	1,527
Shale, sandy	5	1,362	Shale	32	1,559
Sand and shale breaks	44	1,406	Sand, cut poorly	16	1,585
Shale	11	1,417	Shale	21	1,606
			Shale, sandy	10	1,616
			Shale	5	1,621
			Shale, sandy	5	1,626

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-09-	307		Well DH-64-0	09-315	
Owner: Diamond Alkal Driller: Layne-Tea			Owner: Chambers Count Improvement Dis Driller: Layne-	strict No. 1	
Clay	98	98	Topsoil	5	5
Sand	102	200	Clay	47	52
Clay, sandy	117	317	Sand, brown, fine	9	61
Sand	100	417	Shale	14	75
Sand and shale streaks	260	677	Shale, sandy	30	105
Shale	23	700	Shale	84	189
Sand	28	728	Sand, white, fine	18	207
Sand and shale breaks	189	917	Sand and shale streaks	11	218
Shale and sand streaks	103	1,020	Shale	8	226
Sand and sandy shale	180	1,200	Sand, coarse	25	251
	240		Shale	21	272
Well DH-64-09			Sand, blue	11	283
Owner: Chambers County Improvement Distr	rict No. 1		Shale	6	289
Driller: Layne-Te		5	Sand, white, coarse	51	340
Soil	5	65			
Clay	60		Well DH-64	-09-316	
Sand, white, coarse	22	87	Owner: Sur Driller: Sur		
Clay	12	99	Clay and sand	99	99
Sand layers and shale	17	116		12	111
Shale	8	124	Clay Sand and boulders	42	153
Sand	12	136		184	337
Shale	20	156	Gumbo	95	432
Sand, gray, coarse	25	181	Sand and gravel	2	434
Sand, coarse, and traces of gravel	35	216	Rock	30	464
Shale	10	226	Sandy shale	14	478
Well DH-64-0	9-314		Sand Gumbo	128	606
Owner: Asa V	Vilburn		Sand	18	624
Driller: Amos J			Gumbo	2	626
Soil	2	2	Gumbo		
Clay	58	60	Well DH-6	4-09-318	
Shale and fine sand	9	69	Owner: Crum Driller: Hor	pler Brothers	
Gumbo	21	90		mer wright	30
Gumbo and shale	46	136	Soil and sandy clay	14	44
Sand	20	156	Sand	8	52
			Clay	24	76
			Clay, sandy	24	,,

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-09-318-0	Continued		Well DH-64-	09-321	
Sand	14	90	Owner: Crumple	er Brothers	
Gumbo	22	112	Driller: Home	r Wright	
Sand	17	129	Soil and sand	20	20
Gumbo	33	162	Clay	20	40
Sand	10	172	Shale, sandy	138	178
Gumbo	10	182	Shale, hard	26	204
Sand	6	188	Sand, fine	33	237
Gumbo	3	191	Shale, green	4	241
Sand, white, coarse	24	215	Sand, fine	42	283
Sand, blue, fine, and wood	6	221	Sand, coarse	21	304
Gumbo, light blue	3	224	Well DH-64-0	09-324	
Sand, white, coarse	12	236	Owner: J. O. St		
Shale, sticky	18	254	Driller: C. A. V	Williams	
			Clay, yellow	64	64
Well DH-64-09-3			Gumbo, tough	28	92
Owner: Crumpler Br Driller: Homer W			Shale, sandy	23	115
Sand, soil and clay	76	76	Sand, soft	30	145
Sand	14	90	Gumbo, soft and sand	27	172
Clay, sandy	93	183	Gumbo, tough	16	188
Sand	7	190	Gumbo, soft and sand	22	210
Gumbo	4	194	Gumbo, tough	10	220
Sand	44	238	Sand and shale	20	240
Gumbo	10	248	Gumbo, sticky	41	281
Shale, sandy	34	282	Sand and gumbo	5	286
Sand and boulders	58	340	Sand, hard	28	314
Sand, shale and boulders	68	408	Well DH-64-0	9-327	
Gumbo	24	432	Owner: Crumpler		
Shale, sandy	34	466	Driller: Homer	Wright	
Sand	8	474	Soil and clay	10	10
Gumbo	9	483	Sand	9	19
Sand, coarse	25	508	Clay	б	25
Gumbo	10	518	Sand	10	35
Sand, fine	52	570	Sand and clay	25	60
Sand, coarse	30	600	Sand	16	76
Shale	3	603	Clay, hard	6	82
			Sand	10	92
			Gumbo	17	109
			Sand	21	130

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-09-327-	Continued		Well DH-64-09	-613	
Gumbo	9	139	Owner: Humble Oil & Driller: Lowry Wa		
Sand	6	145	Clay, yellow and white	72	72
Gumbo	40	185	Sand	41	113
Shale, sandy	12	197	Shale	13	126
Sand	44	241	Sand, good	14	140
Gumbo and sand	40	281	Sand, good		140
Well DH-64-09	328		Well DH-64-09		
Owner: Tillman Fi			Owner: John N Driller: Katy Dril		
Driller: Amos Jen		3	Clay and topsoil	137	137
Soil	3 17	20	Sand and clay strips	48	185
Clay	50	70	Clay	63	248
Shale	50	76 75	Shale, sandy	22	270
Gumbo Shale and sand	10	75 85	Clay	50	320
	15	100	Shale, sandy	20	340
Gumbo	10	110	Clay	37	377
Shale and gumbo	85	195	Sand	30	407
Gumbo	9	204	Clay and sand strips	15	422
Shale	3	204	Sand, rocky and clay strips	71	493
Sand, fine		255	Clay	27	520
Gumbo and shale	48	307	Sand	6	526
Gumbo	52 10	307	Clay and sand strips	27	553
Shale and sand			Sand and clay strips	44	597
Sand	83	400	Clay and sand strips	118	715
Gumbo	93	493	Sand	11	726
Sand	17	510	Clay	20	746
Well DH-64-09	-329		Sand and clay strips	85	831
Owner: Temple F			Sand, fine	76	907
Driller: Amos Je			Clay	5	912
Soil	3	3	Sand and clay	33	945
Clay	3	6			
Quicksand	29	35	Well DH-64-0		
Shale	25	60	Owner: Houston Lightin Driller: -	ng & Power Co.	
Gumbo and shale	20	80	Clay, small sand breaks	70	70
Gumbo	120	200	Sand	31	101
Shale	9	209	Clay with small sand breaks	147	248
Sand	8	217	Clay and sandy clay	86	334
			Sand and gravel with clay breaks	71	405

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-09-918-	Continued		Clay	3	1,346
Sand	1	406	Sand and hard streaks	25	1,371
Clay	2	408	Clay	4	1,375
Sand	31	439			
Clay	19	458	Well DH-64-10-	205	
Sand with clay breaks	7	465	Owner: Will I Driller: Amos Jen		
Sand	20	485	Soil	6	6
Sand and hard streaks	126	611	Clay	124	130
Sand, fine	20	631	Sand	15	145
Sandy clay with streaks of sand	15	646	Gumbo, sand and shale	205	350
Clay with sandy clay	31	677	Gumbo	129	479
Sand and clay	8	685	Sand	13	492
Clay, sandy clay, and streaks	37	700			
of sand		722	Well DH-64-10-	206	
Sand, fine Clay and streaks of sand	15	737 756	Owner: H, C, I Driller: C, A, Wil		
•	19	808	Clay, red	150	150
Sand and streaks of clay	52		Gumbo	20	170
Sand and sandy clay	50	858	Sand, fine	10	180
Clay and sandy clay	113	971	Gumbo	30	210
Sand, fine	19	990	Sand	10	220
Clay	8	998	Gumbo, hard	60	280
Sand	60	1,058	Shale, soft	25	305
Sand and streaks of clay	19	1,077	Sand, coarse	35	340
Clay and sandy clay	11	1,088	Sand, fine	30	370
Sand	5	1,093	care, me	30	370
Clay and sandy clay with streaks of sand	22	1,115	Well DH-64-10-	302	
Sand and streaks of clay	25	1,140	Owner: Mayes E Driller: Texas Highw		
Sand	7	1,147	Soil, black, sandy		
Sandy clay with streaks of clay	29	1,176	Clay, gray, soft, sandy	3 4	3 7
Clay and sandy clay	21	1,197	Clay, yellow, sticky	2	
Sand, fine	19	1,216	Sand, yellow, water	14	9 23
Clay and sandy clay	10	1,226	Sand, water		
Sand	63	1,289	Clay, brown and gray, sandy	8	31
Clay	9	1,298	with small shells	8	39
Clay	8	1,306	Clay, brown and blue	2	41
Sand	6	1,312	Clay, brown and blue streaked	15	56
Sandy clay and hard streaks	9	1,321	Clay, brown and blue streaked hard	2	58
Sand	22	1,343			

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

Well DH-64-10-302—Continued Sand 15 346 Clay, hard, light-brown streaked 1 59 Shale 8 354 Clay, light-blue streaked 10 69 Sand 8 362 Clay, blue, sandy, soft 1 70 Shale 68 430 Sand, blue, water 8 78 Shale, sandy 10 440 Sand, blue, soft, water 8 86 Shale 30 470 Sand, blue, water 2 88 Sand 18 488 Clay, blue 1 89 Well DH-64-10-406 Well DH-64-10-406 Owner: Jack Rosenau Driller: Jim Avera Owner: Jack Rosenau Driller: Jim Avera 13 120 Owner: Jack Rosenau Driller: Jim Avera 118 118 118 118 118 118 118 128 118 118 118 118 120 Owner: Jack Rosenau Driller: Jim Avera 10 128 128 128 128 128 128 128 128 138 148 <t< th=""></t<>
Clay, light-brown streaked 10 69 Sand 8 362 Clay, blue, sandy, soft 1 70 Shale 68 430 Sand, blue, water 8 78 Shale, sandy 10 440 Sand, blue, soft, water 8 86 Shale 30 470 Sand, blue, water 2 88 Sand 18 488 Clay, blue 1 89 Well DH-64-10-406 Sand, blue, water 31 120 Clay, blue 7 127 Owner: Jack Rosenau Driller: Jim Avera Clay, blue, water 7 134 Clay 118 118 Clay, blue, soft, sandy 1 135 Shale, sandy 10 128 Sand, blue, water 13 148 Sand, water 21 149
Clay, blue, sandy, soft 1 70 Shale 68 430 Sand, blue, water 8 78 Shale, sandy 10 440 Sand, blue, soft, water 8 86 Shale 30 470 Sand, blue, water 2 88 Sand 18 488 Clay, blue 1 89 Well DH-64-10-406 Sand, blue, water 31 120 Owner: Jack Rosenau Driller: Jim Avera Clay, blue 7 127 Owner: Jack Rosenau Driller: Jim Avera Sand, blue, water 7 134 Clay 118 118 Clay, blue, soft, sandy 1 135 Shale, sandy 10 128 Sand, blue, water 13 148 Sand, water 21 149
Clay, blue, sandy, soft Sand, blue, water 8
Sand, blue, water 8 78 Shale, sandy 10 440 Sand, blue, soft, water 8 86 Shale 30 470 Sand, blue, water 2 88 Sand 18 488 Clay, blue 1 89 Well DH-64-10-406 Well DH-64-10-406 Well DH-64-10-406 Sand, blue, water 7 127 Owner: Jack Rosenau Driller: Jim Avera Driller: Jim Avera Sand, blue, water 7 134 Clay 118 118 118 118 Clay, blue, soft, sandy 10 128 Sand, blue, water 21 149
Sand, blue, water 8 86 Sand 18 488 Sand, blue, water 2 88 Sand 18 488 Clay, blue 1 89 Well DH-64-10-406 Sand, blue, water Owner: Jack Rosenau Driller: Jim Avera Clay, blue 7 127 Driller: Jim Avera 118 118 Sand, blue, water 7 134 Clay 118 118 Clay, blue, soft, sandy 1 135 Shale, sandy 10 128 Sand, blue, water 13 148 Sand, water 21 149
Sand, blue, water 2 88 Sand 18 488 Clay, blue 1 89 Well DH-64-10-406 Well DH-64-10-406 Sand, blue, water 7 127 Owner: Jack Rosenau Driller: Jim Avera Sand, blue, water 7 134 Clay 118 118 Clay, blue, soft, sandy 1 135 Shale, sandy 10 128 Sand, blue, water 13 148 Sand, water 21 149
Sand, blue, water 31 120 Owner: Jack Rosenau Driller: Jim Avera Clay, blue 7 127 Driller: Jim Avera Sand, blue, water 7 134 Clay 118 118 Clay, blue, soft, sandy 1 135 Shale, sandy 10 128 Sand, blue, water 13 148 Sand, water 21 149
Sand, blue, water 31 120 Owner: Jack Rosenau Driller: Jim Avera Clay, blue 7 127 Driller: Jim Avera Sand, blue, water 7 134 Clay 118 118 Clay, blue, soft, sandy 1 135 Shale, sandy 10 128 Sand, blue, water 13 148 Sand, water 21 149
Clay, blue 7 127 Driller: Jim Avera Sand, blue, water 7 134 Clay 118 118 Clay, blue, soft, sandy 1 135 Shale, sandy 10 128 Sand, blue, water 13 148 Sand, water 21 149
Clay, blue, soft, sandy 1 135 Shale, sandy 10 128 Sand, blue, water 13 148 Sand, water 21 149
Sand, blue, water 13 148 Sand, water 21 149
Sand, blue, water
Well DU 64 40 409
Owner: Finger Furniture Co. Oriller: Katy Drilling Co. Owner: Ben Dutton Driller: Amos Jennische
Topsoil and clay 132 132 Soil 3 3
Sand and clay strips 58 190 Clay 93 96
Clay 45 235 Shale 22 118
Sand, real fine 12 247 Sand 25 143
Clay, blue 83 330
Sand 61 391 Well DH-64:10-501
Clay 52 443 Owner: C. T. Joseph, Jr. Driller: Katy Drilling Co.
Sand, fine 63 506 Topsoil and clay 110 110
Clay and sand strips 54 560 Sand 23 133
Clay 30 590 _{Clay} 38 171
Sand 7 597 Sand 98 269
Clay and sand strip 68 665 Clay 10 279
Sand, rock, and clay strips 51 716 Sand 31 310
Clay and sand strips 39 755 Clay 35 345
Sand, rocky and clay 116 871 Sand, shale 22 367
Well DH-64-10-405 Sand 20 387
Clay 28 415 Owner: C. O. Williams
Driller: Jim Avera Shale, soft 32 447
Sand 2 2 Sand and shell 19 466
Clay 85 87 Clay 13 479
Sand, coarse 40 127 Shale, soft 49 528
Shale 204 331

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-10-501-	Continued		Gumbo and shale	147	265
Shale, soft, and sandy strips	38	566	Shale, sandy	10	275
Shale and small clay strips	35	601	Gumbo	70	345
Sand	15	616	Sand	15	360
Shale	112	728	Gumbo	120	480
Sand, rocky	181	909	Sand	28	508
Shale	1	910			
No record	2	912	Well DH-64-10	0-514	
			Owner: Mayes Driller: Texas High		
Well DH-64-10			Clay, brownish-yellow and shell	1	1
Owner: Ernest W Driller: Amos Jer			Clay, yellow, soft, brown	1	2
Soil	3	3	Clay, yellow	1	3
Clay	112	115	Clay, yellow and gray and		
Sand	6	121	some white gravel	1	4
Gumbo	6	127	Clay, yellow and gray	4	8
Rock and boulders	8	135	Clay, yellow and gray, sandy	1	9
Gumbo	50	185	Clay, yellow and gray	4	13
Shale	19	204	Clay, yellow and gray, sandy	1	14
Sand	18	222	Clay, yellow with white gravel	3	17
			Clay, gray and yellow	4	21
Well DH-64-10-511			Clay, yellowish-blue and gray	1	22
Owner: Hugh W Driller: Jim Av			Clay, red, yellow and blue	3	25
Clay	94	94	Clay, red, yellow and blue, sandy, water	1	26
Sand, water	24	118	Clay, red and gray	5	31
Shale with sand streaks	42	160	Clay, yellow and blue	10	41
Shale, sticky	110	270	Clay, blue and brown	5	46
Shale, sandy	8	278			
Shale, sticky	62	340	Well DH-64-10	-516	
Sand, water	26	366	Owner: C. T. Josep Driller: Jim A		
Shale, sticky	39	405	Soil	2	2
Shale, sandy	7	412	Clay	146	148
Shale, sticky	63	475	Sand	12	160
Sand, water	26	501	Shale	118	278
			Sand	5	283
Well DH-64-10-			Shale	62	345
Owner: C. T. Joseph Driller: Amos Jen	n Estate nische		Sand	8	353
Clay	98	98	Shale	145	498
Sand	20	118	Sand	14	512

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-10-	702		Gravel	2	350
Owner: Texas Oil and	d Gas Co.		Shale, sandy	12	362
Driller: Homer W	right		Sand	4	366
Clay and sand	185	185	Clay	18	384
Sand	27	212	Sand and gravel	1	385
Shale and sand	105	317	Clay	2	387
Sand	25	342	Sand, fine	3	390
Shale	58	400	Clay, sandy	3	393
Sand	75	475	Clay	7	400
Well DH-64-10	703		Sand and gravel, water	43	443
Owner: V. A. La Driller: Pitre Wate	wrence er Wells		Well DH-64		
Clay	71	71	Owner: V. A. Driller: Luthe		
Sand	3	74	Surface	24	24
Gravel	1	75	Shale	124	148
Clay	15	90	Sand	49	197
Clay, sandy	8	98	Shale	11	208
Gravel	2	100	Sand	44	252
Clay, sandy	14	114	Shale	133	385
Sand	7	121	Sand, water	44	429
Clay	4	125			
Sand, fine	16	141	Well DH-6		
Clay	7	148	Owner: Amos L Driller: Amo	awrence Estate s Jennische	
Sand, fine	7	155	Soil	3	3
Clay	19	174	Shale	52	55
Clay, fine sand with lens of clay	31	205	Sand	5	60
Clay	29	234	Shale	10	70
Clay with lens of sand and gravel	16	250	Gumbo, soft	65	135
Sand	12	262	Sand	10	145
Clay	2	264	Gumbo	60	205
Sand, fine, water	4	268	Sand, fine	25	230
Sand, coarse, water	10	278	Gumbo, soft	43	273
Gravel, water	6	284	Gumbo and rock	2	275
Sand, fine, water	6	290	Sand	25	300
Clay, blue	15	305	Gumbo	65	365
Sand	10	315	Sand	34	399
Clay, sandy	5	320			
Sand and gravel	19	339			
Clay	9	348			

Table 5.-Drillers' Logs of Wells in Chambers and Jefferson Counties-Continued

	т	HICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
	Well DH-64-11-105				Well DH-64-11-401	
	Owner: A. H. Stade Driller: B & L Water Wo	ells		t	Owner: E. S. Abshier Driller: Katy Drilling Co.	
Clay		9	9	Topsoil	5	5
Sand		25	34	Sand	25	30
Shale		76	110	Clay	82	112
Sand		20	130	Sand	30	142
Shale		33	163	Clay	65	207
Sand		15	178	Sand	12	219
				Clay	10	229
	Well DH-64-11-205			Sand	40	269
	Owner: Stanolind Oil and O Driller: Pitre Water We			Clay	71	340
Clay		31	31	Sand	42	382
Sand, water		17	48	Clay	110	492
Clay, tough		19	67	Sand, rocky	38	530
Sand, fine		34	101	Clay	10	540
Clay		9	110	Sand, rocky	27	567
Sand, water		26	136	Clay	11	578
Shale		23	159	Sand and clay	17	595
Sand		3	162			
Shale		7	169		Well DH-64-11-502	
Sand, water		6	175		Owner: Sun Oil Co. Driller: Sun Oil Co.	
Clay, tough		23	198	Sand, surface and cla	y 108	108
Sand		3	201	Shale, gravel and sand	d 88	196
Shale		12	213	Shale and gravel	420	616
Shale, sandy		7	220	Shale	100	716
Sand		1	221	Shale and sand	244	960
Shale, sandy		6	227	Sand and gravel	130	1,090
	Well DH-64-11-206			Shale and sand	162	1,252
	Owner: Stanolind Oil and O Driller: Layne-Texas C				Well DH-64-11-802	
Clay		11	11		ner: City of Anahuac Well 1 iller: Big State Drilling Co.	
Sand		43	54	Surface soil	2	2
Clay		29	83	Clay	3	5
Sand		23	106	Clay and sand	15	20
Clay		11	117	Clay	10	30
Sand		19	136	Shale	40	70
Clay		4	140	Clay	10	80
				-		

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-11-802-	Continued		Well DH-64-12	-204	
Sand, water	40	120	Owner: C. A. F Driller: J. E. Al		
Clay, sandy	10	130		4	4
Shale	20	150	Soil	8	12
Shale, sandy	48	198	Sand	22	34
Clay	2	200	Said		
Sand	5	205	Well DH-64-12	2-206	
Shale, sandy	120	325	Owner: C. J. Mo Driller: Andy Fr		
Sand, poor	25	350	Surface sand	2	2
Shale	10	360		52	54
Sand and shale, layers	60	420	Clay, yellow	26	80
Shale	20	440	Sand, fine Gumbo	185	265
Sand, poor	20	460	Sand	15	280
Sand and shale broken layers	59	519	Gumbo	11	291
Well DH-64-1	1.011		Sand	19	310
Owner: L. F. F	ancher		Well DH-64-1	2-303	
Driller: Pitre Wa	97	97	Owner: W. E.		
Clay, vari-colors	25	122	Driller: Pitre Wa		
Sand, fine, white	3	125	Clay, tough, yellow	194	194
Sand and clay, broken			Sand, fine, gray	10	204
Well DH-64-1	11-914		Shale, blue	74	278
Owner: W. H. Driller: Andy F			Sand, fine, gray Shale, blue	10 32	288 320
Surface sand	2	2	Sand, fine, gray	5	325
Clay, yellow	158	160	Shale, gray	20	345
Sand, fine	15	175	Sand, fine, gray	5	350
Gumbo, gray	145	320	Sand, loose, gray	23	373
Sand	20	340	Shale, medium	25	398
Well DH-64-	12-107		Sand, soft, dark-gray, very fine	5	403
Owner: M. P Driller: Andy I			Well DH-64-	12-502	
Surface sand	2	2	Owner: Humble Oil a Driller: Humble Oil a	and Refining Co.	
Clay, yellow	60	62	Clay	91	91
Sand	29	91	Sand and gravel	4	95
	40.400		Clay	35	130
Well DH-64 Owner: Roy & Driller: Pitre V	. Abshier		Sand, water	17	147
Clay	22	22			
Sand, very fine, white	16	38			

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-1	2-704		Well DH-64-	13-601	
Owner: Humble Oil an Driller: L. Pat			Owner: Trinity Bay Conse Driller: Layne-	rvation District Well Texas Co.	1
Clay	22	22	Topsoil	3	3
Sand	25	47	Clay	114	117
Clay	4	51	Sand, coarse	28	145
Sand	8	59	Clay	46	191
Clay	4	63	Sand, fine, gray	21	212
Well DH-64-1	3-102		Clay	49	261
Owner: Sun C	Dil Co.		Well DH-64-	13-602	
Driller: A-1 Wat	er Weils		Owner: Trinity Bay Conse		2
Soil, black surface	4	4	Driller: Layne-		
Clay, yellow	18	22	Clay	115	115
Sand, yellow	3	25	Sand, white	33	148
Shale, yellow	25	50	Clay	41	189
Sand, fine, blue	6	56	Sand, gray	20	209
Shale, sticky	42	98	Clay	52	261
Sand, fine, gray	27	125	Well DH-64-	13-604	
Shale, soft, blue	15	140	Owner: H. M.		
Sand, gray, water	35	175	Driller: V. R		
Well DH-64-1	3-106		Clay	20	20
Owner: Lawrence	Rowland		Sand, blue, fine	80	100
Driller: V. R.			Clay	40	140
Clay	40	40	Sand	22	162
Shell, oyster	20	60	Well DH-64-	13-616	
Clay	46	106	Owner: Sinclair		
Sand	74	180	Driller: Lowry		
Well DH-64-1	3-112		Surface, clay	18	18
Owner: C. B.	Jeffery		Sand, gray	46	64
Driller: Andy F			Shale, blue	61	125
Surface sand	2	2	Sand, good	25	150
Clay, yellow	103	105	Shale, soft	2	152
Sand, and clay, fine	15	120	Well DH-64-	13-617	
Clay, gray	39	159	Owner: Wilson		
Sand	17	176	Driller: Green Bros. W		
			Clay, yellow	16	16
			Sand, white	34	50

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

		CKNESS FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
	Well DH-64-14-102			Shale	5	332
	Owner: S. J. Ryan Driller: Pitre Water Wells			Sand	66	398
Clay, medium		20	20	Well DH-64-17-	304	
Sand, fine		29	49	Owner: The Texa Driller: Pitre Wate		
Clay, medium		64	113	Clay, medium	64	64
Sand, coarse		35	148	Sand, soft	44	108
Clay, medium		8	156	Shale, blue and shell	75	183
Sand, soft		20	176	Sand, white fine	37	220
Clay, medium		22	198	Shale with coarse sand	178	398
	Well DH-64-14-704			Shale, hard	120	518
	Owner: J. B. Myers			Sand, hard	47	565
	Driller: V. R. Phelps			No record	19	584
Clay		35	35			
Quicksand		4	39	Well DH-64-17-		
Clay		150	189	Owner: The Tex Driller: Pitre Wate		
Sand		8	197	Clay, medium red	40	40
	Well DH-64-17-212			Shale, medium blue	25	65
	Owner: C. Vickers			Shale, medium blue and sand	15	80
	Driller: Amos Jennische			Sand, rough, white and gravel	28	108
Clay		74	74	Shale, blue, sticky	36	144
Sand		29	103	Sand, medium fine, blue and shale	31	175
Shale		37	140	Shale, medium blue, sandy	44	219
Shale and gumbo		60	200	Shale, medium blue	32	251
Gumbo		125	325	Sand, medium white, rough, fine	22	273
Sand, fine and sha	le	10	335	Sand, soft, white, fine	22	295
Sand		11	346	Clay, sticky, blue	49	344
	Well DH-64-17-302			Sand, rough, white	28	372
	Owner: The Texas Co. Driller: Pitre Water Wells			Well DH-64-17	-307	
Clay, red		71	71	Owner: Odell F Driller: Amos Jer		
Sand		28	99		3	3
Shale, blue		8	107	Soil	77	80
Sand, hard		13	120	Clay	16	96
Shale, blue		92	212	Sand	16	96
Sand, hard		47	259			
Shale, blue		61	320			
Sand, hard		7	327			

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-17	7-308		Sand	5	595
Owner: B, D, F			Shale	26	621
Driller: Amos Je			Sand, broken and shale layers	14	635
Soil	3	3	Shale and sandy shale	58	693
Clay	77	80	Shale	18	711
Sand	17	97	Sand, broken	20	731
Well DH-64-17	'-601		Shale	28	759
Owner: Asa Wi			Sand	80	839
Driller: Amos Je			Shale	6	845
Soil	3	3	Sand-fine and shale breaks	30	875
Clay	71	74	Shale, hard	32	907
Şand	20	94	Sand	5	912
Well DH-64-17	-607		Shale, sandy	12	924
Owner: J. C. F			Sand	6	930
Driller: Amos Je	nnische		Shale, hard	20	950
Soil	3	3	Sand, fine	35	985
Clay	12	15	Shale	8	993
Quicksand	5	20	Sand	25	1,018
Clay	10	30	Shale	8	1,026
Quicksand	15	45	Sand	6	1,032
Clay	50	95	Shale, sandy	9	1,041
Sand	10	105	Sand and shale streaks	80	1,121
Well DH-64-17	-610		Shale	17	1,138
Owner: Jones & Laugh	lin Steel Co.		Sand and shale streaks	52	1,190
Driller: Layne-Te			Shale, hard	29	1,219
Clay	75	75	Sand and shale streaks	39	1,258
Clay, sandy	16	91	Shale	48	1,306
Sand, broken	29	120	Sand	26	1,332
Shale	30	150	Shale	8	1,340
Sand and shale layers	35	185	Sand	58	1,398
Shale and sandy	46	231	Shale	4	1,402
Sand, broken and shale	10	241	Sand	32	1,434
Shale	146	387	Shale and sandy shale	7	1,441
Shale, sandy	8	395	Sand and shale streaks	54	1,495
Shale	38	433	Shale and sandy shale	18	1,513
Sand and shale streaks	9	442			
Shale	50	492			
Sand and shale streaks	93	585			
Shale	5	590			

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-17	-901		Well DH-64-1	18-107	
Owner: Seacres			Owner: Irvin Driller: Amos J		
Driller: Pitre Water	er Wells 18	18	Soil	3	3
Sand	7	25	Clay	122	125
Clay	25	50	Sand and shale	5	130
Sand	17	67	Gumbo	20	150
Shale	63	130	Sand	25	175
Sand	8	138	Shale	15	190
Clay Sand and shale	12	150	Gumbo	35	225
Sand and shale Sand, soft, green, and shale	80	230	Sand	30	255
Clay, medium red	13	243	Gumbo and shale	45	300
	8	251	Sand	42	342
Sand, soft gray Shale, medium blue	43	294	Gumbo	58	400
Shale, medium blue Shale, soft green	36	330	Sand	70	470
Shale, hard blue, boulders	53	383	Gumbo	140	610
Shale, soft gray	11	394	Sand	24	634
Gumbo, medium blue	42	436			
Shale, medium green and sand	15	451	Well DH-64		
Shale, medium shale and sand	13	464	Owner: W. F. Driller: Jin	Lawrence Avera	
Shale, medium blue	28	492	Clay	125	125
Sand, soft gray	43	535	Shale	25	150
Shale, medium blue	19	554	Shale, fine and sand streaks	16	166
Sand, soft gray	63	617	Sand, fine	30	196
Clay, red medium	15	632		40.407	
Sand, fine, soft gray, water	68	700	Well DH-64		
Shale, medium blue	3	703	Owner: F. A. F Driller: C. A		
No Record	6	709	Clay	10	10
			Sand, yellow	20	30
Well DH-64-			Gumbo	170	200
Owner: E. E. Driller: Luther			Sand	40	240
Surface	24	24	Gumbo	40	280
Shale	197	221	Sand and boulders	77	357
Sand	22	243	Gumbo and boulders	36	393
Shale	43	286	Shale and boulders	44	437
Sand	54	340	Gumbo, hard and lime	13	450
			Shale	13	463
			Sand, hard	2	465

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)			CKNESS EET)	DEPTH (FEET)
Well DH-6	64-18-407—Continued		Shale, hard		9	338
Shale	2	467	Shale, soft		11	349
Rock	3	470	Sand		7	356
Shale and boulders	4	474	Gumbo		13	369
Shale, sandy	34	508	Clay		7	376
Shale, hard	20	528	Gumbo		23	399
Sand	60	588	Sand		33	432
Shale	11	599	Gumbo		4	436
Gumbo	6	605	Clay		6	442
Sand, hard	5	610	Sand and gravel		32	474
Shale, hard and lime	95	705	Clay, blue		29	503
Shale, broken and sand	25	730	Shale		33	536
Sand	25	755	Sand		18	554
			Gumbo		26	580
	DH-64-19-204		Shale		19	599
	ble Oil and Refining Co. Pitre Water Wells		Gumbo		42	641
Clay, medium	72	72	Shale, blue		3	644
Clay, hard	60	132	Clay, tough		56	700
Sand, fine, soft	13	145	Gumbo		57	757
Clay, hard	13	158	Shale		20	777
			Sand		8	785
Well	DH-64-19-308		Gumbo		15	800
	Layne-Bowler Co. Layne-Bowler Co.		Sand		12	812
Loam	2	2	"Hard Pan"		8	820
Clay	8	10	Sand and gravel		31	851
Sand	24	34	Gumbo		18	869
Clay	10	44	No record		181	1,050
Sand	39	83		Well DH-64-19-609		
Clay	19	102		Owner: Charlie Gilfillian		
Gumbo	48	150		Driller: R. H. Schneider		
Shale, hard	19	169	Clay, yellow		24	24
Shale, soft	15	184	Shale, blue		16	40
Shale, hard	13	197	Shale, pink		22	62
Gumbo	7	204	Sand, fine		19	81
Sand	46	250		Well DH-64-19-911		
Gumbo, blue	13	263				
Sand	43	306		Owner: E. A. Wilburn Driller: Andy Frankland		
Gumbo, blue	23	329	Clay, yellow		18	18
			Sand, fine		6	24

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-19-911-	-Continued		Well DH-64-2	1-204	
Clay, soft gray	254	278	Owner: Frost (Driller: Pitre Wa		
Sand, streaks	11	289	Clay, medium yellow	22	22
Clay, blue	15	304	Sand, fine, soft	17	39
Sand with clay streaks	22	326	Clay, soft sandy	44	83
= 04.0	. 400		Sand, fine, soft	17	100
Well DH-64-2			Shale, medium	58	158
Owner: Mrs. James Driller: Andy Fr	ankland		Sand, medium soft	17	175
Surface sand	24	24	Sand, coarse and gravel	9	184
Clay, yellow	61	85	Clay, medium	11	195
Sand, fine	20	105	Well DH-64-2	21,301	
Clay, gray	165	270	Owner: Sun		
Sand	4	274	Driller: A-1 Wa	ter Wells	
Clay, soft	256	530	Soil, surface black	2	2
Sand	19	549	Clay, yellow	16	18
Well DH-64-	20-601		Sand, fine, yellow	12	30
Owner: Sun	Oil Co.		Sand, fine, blue	35	65
Driller: R. H. S	Schneider		Shale, blue	91	156
Clay, yellow	20	20	Sand, water	38	194
Shale, blue	62	82	Well DH-64-	21-306	
Sand	16	98	Owner: Sun		
Shale, blue	92	190	Driller		
Sand	24	214	Surface soil, black	2	2
Well DH-64	20-804		Clay, yellow	20	22
Owner: Guy Driller: Amos	Jackson Jennische		Sands, fine yellow	11	33
Soil	3	3	Well DH-64		
Clay	77	80	Owner: Prince Driller: Pitre V	Drilling Co. Vater Wells	
Clay and shale	100	180	Sand	18	18
Gumbo	40	220	Shale	22	4 0
Shale	80	300	Unknown	20	60
Sand	6	306	Sand	96	156
Shale	48	354	Sand, fine	24	180
Sand	6	360	Shale	6	186
Gumbo	15	375			
Sand	45	420			

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well DH-64-26-707				Well DH-64-27-702	
Owner: Humble Oil and Driller: Humble Oil and	Refining Co. Refining Co.			Owner: S. W. Mahoney Driller: Andy Frankland	
Sand and shale	456	456	Surface sand	30	30
Shale, sandy	27	483	Clay, soft gray	60	90
Sand	74	557	Sand	36	126
Well DH-64-26-708				Jefferson County	
Owner: Humble Oil and I Driller: Humble Oil and I	Refining Co. Refining Co.			Well PT-61-56-702	
Shell and clay	160	160		Owner: Beaumont Country Club Driller: Layne-Texas Co.	
Sand and clay	130	290	Clay, sandy	22	22
Shale	183	473	Clay, tough	184	206
Sand and gravel	43	516	Sand, white	41	247
Shale	85	601	Clay	30	277
Sand	15	616	Clay, sandy	37	314
Shale	29	645	Sand	26	340
Gravel	18	663	Clay	28	368
Sand	47	710	Clay, sandy	16	384
No record	8	718	Sand	20	404
Well DH-64-26-9	05		Shale	130	534
Owner: J. E. Patt Driller: Pitre Water				Well PT-61-61-807	
Sand, brown	6	6		Owner: Southern Pacific Co. Driller: Gust C. Warnecke	
Clay, broken black	11/4	71/2	Clay	19	19
Sand, powder brown	10	171/2	Sand	84	103
Log, brown	1/4	18	Clay	4	107
Sand, fine, vari-color	12	30	Sand	16	123
Shell, oyster and sand	3	33	Clay	46	169
Well DH-64-27-20	17		Sand	12	181
	-		Clay	49	230
Owner: McCarthy Oi Driller: Pitre Water V			Loam, sandy	129	359
Sand, soft gray, fine	33	33	Sand	21	380
Clay, medium red	7	40	Clay	40	420
Clay, medium red, and sand	20	60	Sand	40	460
Shale, medium green	25	85	Shale, soft	182	642
Sand, soft gray, fine	115	200	Sand, water	50	692
Sand, medium green and shale	22	222			
Sand, soft gray	46	268			
No record	146	414			

Table 5.—Drillers Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well PT-61-64-5	501		Sand	47	156
Owner: Mobil Oi			Gumbo	9	165
Driller: Layne-Tex			Sand	50	215
Soil, surface and clay	25	25	Shale	34	249
Sand, red	28	53	Sand	9	258
Shale	62	115	Gumbo	5	263
Sand, gray	30	145	Sand and shale	45	308
Shale	209	354	Gumbo	16	324
Sand and shale layers	32	386	Sand and shale	65	389
Shale, sandy	45	431	Gumbo	28	417
Sand	25	456	Sand	20	437
Shale	39	495	Gumbo	59	496
Sand	10	505	Sand with gravel at bottom	145	641
Shale	3	508			
Sand, water	110	618	Well PT-61-	64-505	
Shale	2	620	Owner: Mobil Driller: Texas Wat	l Oil Co. er Wells, Inc.	
Well PT-61-64-	502		Surface	4	4
Owner: Gulf States U			Clay	28	32
Driller: Coastal Wa	ter Wells		Sand	7	39
Topsoil	5	5	Shale	32	71
Sand	25	30	Sand	14	85
Shale	60	90	Shale	11	96
Shale and sand	30	120	Sand	51	147
Shale	30	150	Shale	153	300
Sand, fine	40	190	Shale, sandy	56	356
No record	40	230	Shale	56	412
Sand, coarse	30	260	Sand	35	447
No record	270	530	Shale	61	508
Shale, sandy	100	630	Sand	125	633
			Sand, shale streaked	27	660
Well PT-61-64			Sand	178	838
Owner: Olin Math Driller: Frank	ieson Co. Balcar		Shale, sandy	71	909
Clay	18	18	Situlo, salidy		
Sand	4	22	Well PT-61	-64-506	
Shale	11	33	Owner: Mob Driller: Texas Wa	oil Oil Co. ater Wells, Inc.	
Gumbo	19	52	Surface	7	7
Sand	10	62	Clay	24	31
Gumbo	47	109	Sand, fine	3	34

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

		THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
	Well PT-61-64-506-0	ontinued		Shale, sandy	55	125
Sand, clay str	reaks	64	98	Gumbo	45	170
Sand, gray		50	148	Sand, medium	75	245
Clay		255	403	Gumbo	3	248
Sand, fine, ha	ard	54	457			
Shale		51	508	Well PT-61-64	-513	
Sand, fine har	rd	45	553	Owner: Mobil O Driller: Layne-Te	il Co. xas Co.	
Shale, sand st	reaks	41	594	Surface soil	3	3
Sand, fine, ha	rd	39	633	Clay	68	71
Shale		29	662	Sand	12	83
Sand, very ha	rd	171	833	Clay	13	96
Shale, sandy		63	896	Sand and clay, streaks	12	108
Shale		12	908	Sand	40	148
	Well PT-61-64-5	ne .		Clay	5	153
	Owner: Gulf States Uti			Sand, broken	20	173
	Driller: Coastal Wate	r Wells		Shale, sandy	3	176
Sand		15	15	Shale, sandy and sand, streaks	49	225
Gumbo		30	45	Sand	11	236
Sand		15	60	Clay, sandy	28	264
Gumbo		13	73	Sand and clay	17	281
Shale		87	160	Clay, sandy	31	312
Sand		100	260	Sand and clay, streaks	29	341
Shale		60	320	Sand and clay	20	361
Sand		30	350	Sand and clay, streaks	84	445
Shale		40	390	Clay, sandy	12	457
Sand		50	440	Sand, coarse	25	482
Shale		40	480	Shale and sand, streaks	32	514
Sand		80	560	Sand, hard, and shale, streaks	122	636
Shale, sandy		240	800	Shale	4	640
Shale, gummy		800	1,600	Wall DT C4 C4 C4		
Sand, fine		12	1,612	Well PT-61-64-8		
	Well PT-61-64-51	0		Owner: Philip Br Driller: Higgins Oil and	ros. I Fuel Co.	
	Owner: Gulf States Utili			Soil, black sandy loam	1	1
04	Driller: Coastal Water			Clay, yellow with red streaks	13	14
Sand		19	19	Clay, blue with limy concretions	2	16
Gumbo		24	43	Sand, bluish-gray	6	22
Sand		18	61	Clay, yellowish-colored with lime	8	30
Gumbo		9	70	Clay, dark-blue with lime and shells	10	40

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well PT-61-64-803-0	Continued		Lignite	5	920
Sand, gray	16	56	Sand, bluish-gray with shells	34	954
Sand, blue	13	69	Rock, bluish-gray	4	958
Clay, blue with pyrites	51	120	Sand, very fine, grayish-brown, with shells	24	982
Sand, blue with some clay and small pebbles	26	146	Sand, very fine, with shells	13	995
Sand, fine bluish-gray	10	156	Rock, dark gray, "Cap Rock"	5	1,000
Sand, fine gray	31	187	Sand, coarse, dark-gray with oil	6	1,006
Sand, fine gray with black specks	10	197	Well PT-61-6	4-804	
Sand, bluish-tinted gray	65	262	Owner: McFadden,	Wiess & Kyle	
Sand, dark-gray with black specks	9	271	Driller: J. G. & A.	W. Hamill	
Sand, fine, dark-gray	44	315	Clay, yellow	36	36
Sand, fine grayish-tinted	35	350	Sand, coarse, gray	20	56
Sand, fine, grayish-green	50	400	Clay, blue, hard	114	170
Sand, fine, brownish-gray	40	440	Sand, fine, gray	75	245
Sand, fine brown with shells	30	470	Gravel, vari-colored	20	265
Sand, fine, brown with			Sand, coarse, gray	52	317
broken shells	21	491	Clay, blue	35	352
Sand, coarse, blue with broken shells	9	500	Sand, coarse gray with pyrite concretions	24	376
Sand, very fine, muddy	47	547	Clay, blue	19	395
Sand, very fine, bluish-gray	17	564	Sand, fine, gray with lignite	45	440
Sand, very fine, gray with bluish tint	48	612	Mari	8	448
Sand, fine, gray with bluish tint	12	624	Sand, gray with concretions and much lignite	60	508
Clay, fine, sandy (fishbones at 628 feet)	42	666	Limestone, soft	%	508%
Clay, fine, blue, sandy	6	672	Clay, gray and sulphurated hydrogen gas	19%	528%
Sand, very fine, light blue	13	685	Sandstone, hard with calcite		
Rock, light blue	43	728	depositions	%	529
Sand, bluish-gray	8	736	Sand, gray	34	563
Sand, light gray with shells	14	750	Sand, compact hard with pyrite	25	588
Marl with small shells	6	756	Sandstone, hard and calcareous concretions	1/2	588%
Sand, light bluish-gray and shells	5	761	Clay, gray	13%	601%
Sand, fine and shells	64	825	Sand, hard	1/4	602
Sand, very fine, dark brownish-gray	49	874	Clay, gray with calcareous concretions	57	659
Clay, hard, grayish-blue, sandy with shells	26	900	Shells, white, calcareous	6	665
Rock, dark-2 feet, shells-1 foot	3	903	Clay, gray	14	679
Sand, dark grayish-blue with some clay	12	915	Sandstone, gray	6	685

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well PT-61-64-804-0	Continued		Sand	28	97
Clay, gray, with calcareous	_		Clay	51	148
concretions	7	692	Sand	13	161
Clay, gray, hard	23	715	Clay	4	165
Concretions, calcareous	2	717	Sand	20	185
Clay, hard, gray, with calcareous concretions and fine pyrite	136	853	Clay and streaks of sand	263	448
Sandstone and pyrite, hard	20	873	Sand, broken	42	490
Rock, hard, limestone	2	875	Clay	7	497
Sand, fine, oil	24	899	Sand (good)	53	550
Clay, hard	80	979	Well PT-61-64	003	
Sandstone, hard with calcareous concretions	50	1,029			
Gas, heavy pressure and oil	40	1,069	Owner: Big Three Indu Driller: Layne-Te		
Sand, mixed with calcareous	40	1,069	Top soil	3	3
concretions and fossils	70	1,139	Clay	18	21
No record	21	1,160	Sand	14	35
Well PT-61-64-9	101		Clay	35	70
			Sand and sandy clay	83	153
Owner: Air Reduction (Driller: Layne-Tex			Sand and streaks of clay	57	210
Surface soil	3	3	Sandy clay and streaks of sand	240	450
Clay, sandy	57	60	Sand	22	472
Clay	11	71	Clay	11	483
Sand	31	102	Sand	107	590
Clay, sandy	47	149	W-II DT 64 64	004	
Sand	12	161	Well PT-61-64-		
Clay	5	166	Owner: Big Three Indus Driller: Layne-Te		
Sand	20	186	Top soil	3	3
Clay and sand streaks	215	401	Clay	57	60
Clay, sandy and sand streaks	51	452	Sand	34	94
Sand, coarse	34	486	Clay	15	109
Clay	4	490	Sand, clay and sandy clay	49	158
Sand, fine	4	494	Sand, shell and sandy clay	68	226
Clay	6	500	Clay	20	246
Sand, coarse (very good)	20	520	Clay and sandy clay	108	354
No record	20	540	Clay, sandy and clay	21	375
Well PT-61-64-9	02		Clay	69	444
			Sand	23	467
Owner: Air Reduction C Driller: Layne-Texa			Clay	10	477
Surface soil	4	4	Sand, salt and pepper	284	761
Clay, sandy	65	69	Clay, sandy	19	780

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNES (FEET)	S DEPTH (FEET)		т	HICKNESS (FEET)	DEPTH (FEET)
,	Well PT-62-57-703		,	Well PT-62-57-706		
0	wner: Pure Oil Co. Driller:Walling		C	Owner: Pure Oil Co. Driller:Walling		
Clay	38	38	Sand and clay		150	150
Sand and shale	73	111	Sand		22	172
Sand	15	126	Clay		90	262
Clay	10	136	Sand		21	283
Sand and clay	34	170	Clay		154	437
Clay	56	226	Gumbo		20	457
Sand	8	234	Sand		61	518
Sand and clay	38	272		Well PT-62-57-707		
Clay	18	290		Owner: Pure Oil Co.		
Gumbo	20	310	,	Driller:Walling		
Clay and shale	28	338	Mud		22	22
Clay	42	380	Sand		119	141
Clay and shale	13	393	Mud and sand		41	182
Gumbo	74	467	Mud		41	223
Sand	17	484	Clay		119	342
Sand and clay	22	506	Gumbo		40	382
Sand	102	608	Clay		20	402
	Well PT-62-57-704		Gumbo		47	449
			Sand		66	515
,	Owner: Pure Oil Co. Driller:Walling		Gumbo		29	544
Mud and sand	70	70	Sand		62	606
Clay	45	115		Well PT-62-57-709	,	
Sand	20	135		Owner: Pure Oil Co		
Shale and clay	55	190		Driller:Walling		
Sand and boulders	15	205	Mud and clay		28	28
Sand	15	220	Sand and shale		103	131
Clay	20	240	Clay		39	170
Sand and boulders	28	268	Sand and clay		14	184
Clay	67	335	Gumbo and boulders		44	228
Gumbo	47	382	Clay		17	245
Clay	32	414	Sand		5	250
Gumbo	36	450	Clay		108	358
Sand	68	518	Shale and clay		12	370
Gumbo	23	541	Gumbo		90	460
Sand	61	602	Sand and clay		28	488
			Sand		117	605

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

		THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
	Well PT-62-57-71	0		Sand	52	161
	Owner: Pure Oil C Driller:Walling			Shale	11	172
Clay	Dillier: "Walling	34	34	Gumbo, blue	13	185
Sand and shale		84	118	Shale, gray	60	245
Sand and clay		36	154	Rock, sand	1	246
Gumbo		35	189	Gumbo	24	270
Shale and clay		35	224	Shale, hard	30	300
Clay		31	255	Gumbo	26	326
Sand		21	276	Rock	1	327
Gumbo		61	337	Shale, pink	23	350
Sand and shale		63	400	Gumbo	32	382
Gumbo		27	427	Shale, hard	53	435
Sand and clay		47	474	Shale, soft	23	458
Gumbo		30	504	Shale, sandy	22	480
Sand		106	610	Rock, shale	2	482
				Sand, water	28	510
	Well PT-62-57-713	3		Well PT-63-01	-202	
	Owner: Pure Oil Co Driller:Walling	э.		Owner: City of Por		
Mud		30	30	Driller: Layne-B		
Sand		110	140	Clay	14	14
Sand and mud		40	180	Quicksand	13	27
Clay		65	245	Sand, yellow	41	68
Sand and clay		35	280	Sand, white, fine-grained, water	27	95
Clay		45	325	Clay	83	178
Gumbo		55	380	Sand, black, fine-grained	14	192
Clay		36	416	Clay, yellow	48	240
Gumbo		39	455	Sand, gray, medium-grained	43	283
Sand		61	516	Gumbo, blue	77	360
Gumbo		24	540	Sand, white, coarse-grained	14	374
Sand		66	606	Gumbo, hard	68	442
	Well PT-63-01-104			Pack sand, hard Shale, hard	185	627
	Owner: City of Nederl			Shale, hard	2	629
	Driller: Frank Balca			Well PT-63-01-	204	
Clay, yellow		32	32	Owner: City of Por Driller: Layne-Bo	t Arthur	
Sand		6	38	Clay	14	14
Shale		22	60	Quicksand	17	31
Gumbo		10	70	Clay, yellow	44	75
Shale, blue		39	109		~ ~	, 0

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well PT-63-01-204-0	Continued		Sand, gray, coarse-grained	55	385
Sand, white, coarse-grained,			Gumbo, soft blue	115	500
water	27	102	Sand with layers of gravel	137	637
Gumbo	83	185	Gravel, coarse	7	644
Sand, blue, fine-grained	33	218			
Gumbo, blue	38	256	Well PT-63-	01-302	
Sand, gray, medium-grained	46	302	Owner: Atlantic Driller: Layne-		
Gumbo, blue	18	320	Clay	18	18
Sand, white, medium-grained	32	352	Clay, sandy	8	26
Gumbo, hard	91	443	Clay	45	71
Sand, gray, fine-grained	34	477	Shale	15	86
Gumbo, blue	19	496	Sand, streaks, and shale	12	98
Sand, gray, medium-grained	80	576	Shale	6	104
Sand and gravel	80	656	Sand, water	37	141
Rock	1	657	Shale	36	177
Well PT-63-01-	205		Sand	18	195
Owner: City of Port Arthur			Shale	15	210
Owner: City of Por Driller: Layne-B	owier		Sand	10	220
Topsoil	12	12	Gumbo	34	254
Quicksand	18	30	Shale, sticky	39	293
Gumbo, blue	48	78	Shale and sand streaks	15	308
Sand, blue, fine-grained	30	108	Sand and shale	13	321
Sand, coarse-grained	51	159	Shale, tough, sticky	11	332
Clay, yellow	37	196	Sand and shale	5	337
Sand, blue, fine-grained	58	254	Sand	10	347
Gumbo, blue	59	313	Shale, tough	79	426
Sand, fine-grained	33	346	Sand	26	452
Sand, heavy, white	30	376	Shale	21	473
Gumbo, hard, blue	90	466	Sand layers, and shale	12	485
Sand, blue, fine-grained	20	486	Sand	61	546
Sand, medium-grained and gravel	196	682	Shale	3	549
==			Share		
Well PT-63-01			Well PT-63	-01-303	
Owner: City of Po Driller: Layne-Te			Owner: Atlantic Driller		
Soil	3	3	Clay, yellow	18	18
Clay	80	83	Sand	12	30
Sand, and salt, white, coarse-grained	58	141	Clay, yellow	23	53
Shale, soft blue	189	330	Gumbo, soft	44	97

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well PT-63-01-303-C	ontinued		Sand	2	358
Gumbo, hard	20	117	Shale	65	423
Sand	34	151	Sand	28	451
Gumbo, blue	12	163	Gumbo	15	466
Sand	4	167	Sand	82	548
Gumbo	47	214	Gumbo	52	600
Sand	4	218	Lime, sandy	10	610
Gumbo and shale	264	482	Gumbo, sandy lime streaks	18	628
Sand	30	512	Shale	46	674
Gumbo	40	552	Gumbo	24	698
Sand	38	590	Sand, water	130	828
Gravel	6	596	Gumbo	25	853
Shale, blue	111	707	Sand	207	1,060
Shale, sandy	23	730	Gumbo	47	1,107
Sand	26	756	Shale	220	1,327
Gravel	66	822	Sand	60	1,387
Wall PT 62 01 2	OE.		Gumbo	18	1,405
Well PT-63-01-305			Shale, sticky	20	1,425
Owner: Atlantic Refi Driller: Layne-Texa			Sand	42	1,467
Surface soil	1	1	Shale, sticky	4	1,471
Clay	9	10	Well PT-63-0	1.505	
Clay with sand streaks	51	61	Owner: Texas High		
Shale	18	79	Driller: Layne-T		
Sand, small amount of water	19	98	Surface soil	6	6
Clay	4	102	Clay, blue	57	63
Sand, water	40	142	Sand	34	97
Clay	33	175	Clay	21	118
Sand	18	193	Sand	27	145
Shale	20	213	Clay	24	169
Sand	7	220	Sand	29	198
Gumbo	26	246	Clay and sand streaks	123	321
Shale	5	251	Sand and clay streaks	59	380
Gumbo	12	263	Sand	17	397
Shale and gumbo streaks	50	313	Clay	4	401
Sand	11	324	Sand and clay streaks	21	422
Gumbo	3	327	Clay, sandy and clay streaks	48	470
Sand	12	339	Clay	39	509
Gumbo	17	356	Clay, and sand streaks	31	540

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well PT-63-01-505-			Sand and boulders	59	625
	20	560	Rock, sand	22	647
Sand	40	600	Gumbo	23	670
Sand and hard streaks	40		Sand	14	684
Well PT-63-01	1-606		Gumbo	16	700
Owner: City of Driller: Layne-T	Groves exas Co.		Shale, sandy	15	715
Soil	4	4	Gumbo	88	803
Clay	11	15	Sand, fine-grained	37	840 850
Clay, sandy	45	60	Gravel, coarse	10	860
Clay	25	85	Sand, coarse-grained	10	908
Sand, fine	12	97	Sand, fine-grained	48	900
Clay	26	123	Well PT-63-01-	702	
Sand, fine	3	126	Owner: The Tex	as Co.	
Shale and sandy shale	51	177	Driller:		
Sand, fine	5	182	Surface, clay	54	54
Shale	32	214	Shells	22	76
Shale, sandy	16	230	Shale	41	117
Sand	11	241	Gumbo	90	207
Shale, sandy	230	471	Shale	178	385
Sand	5	476	Gumbo	30	415
Shale, sandy shale, and			Shale, sandy	15	430
streaks of sand	269	745	Gumbo	138	568
Sand	126	871	Shale	81	649
Shale	15	886	Gumbo	26	675
No record	1	887	Shale	25	700
Well PT-63	-01-701		Gumbo	35	735
Owner: The			Shale	19	754
Driller			Gumbo	21	775
Clay, surface	20	20	Shale, sandy	67	842
Sand	10	30	Sand, medium and coarse-grained, water	80	922
Clay and sand	148	178	Gumbo	2	924
Sand and shale	113	291			
Gumbo	18	309	Well PT-63-0	01-703	
Shale, sandy and boulders	131	440	Owner: Olin Mat Driller: Frank	thieson Co. k Balcar	
Shale, hard	50	490		756	756
Gumbo	10	500	No formational record	84	840
Sand	36	536	Gumbo, blue and shale	15	855
Gumbo	30	566	Sand, blue and shale rock	80	935
			Sand and gravel	80	300

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well PT-63-09-1	102		Sand, coarse-grained, water	20	125
Owner: Gulf Refini			Clay	6	131
Driller: Gulf Coast Dr			Sand	5	136
Clay	150	150	Clay	10	146
Sand	30	180	Sand	9	155
Gumbo	36	216	Clay	5	160
Sand	14	230	Clay, soft, sandy	5	165
Gumbo	110	340	Clay	58	223
Sand, and thin layers of lignite	110	450	Sand and shale	22	245
Gumbo	64	514	Shale, sandy and shell	36	281
Sand, hard	44	558	Sand	12	293
Gumbo	30	588	Clay	45	338
Sand	102	690	Sand	20	358
Gumbo	110	800	Shale	17	375
Shale	80	880	Sand	33	408
Sand, coarse-grained, water	64	944	Clay and sand	11	419
Gumbo	2	946	Sand	9	428
W-U PT 62 00 1	100		Clay	12	440
Well PT-63-09-1			Sand	30	470
Owner: Gulf Refini Driller: Gulf Coast Dr			Clay	32	502
Clay, blue and yellow	95	95	Sand	49	551
Shells	21	116	Wood	4	555
Shale	42	158	Sand	16	571
Gumbo	65	223	Clay	109	680
Sand and shale	143	366	Sand	5	685
Sand, hard	102	468	Clay	10	695
Gumbo	68	536			
Shale	18	554	Sand Shale	5	700
Gumbo	46	600		10	710
Shale	80	680	Sand	38	748
Gumbo	100	780	Shale	5	753
Shale	45	825	Sand	16	769
Sand and shale	55	880	Shale	41	810
Sand, water	82	962	Sand	82	892
Gumbo	3	965	Shale	4	896
			Sand and gravel, coarse-grained, water	47	943
Well PT-63-09-2	202		Shale	10	953
Owner: Gulf State Ut Driller: Layne-Tex					
Surface	3	3			
Clay, sandy	102	105			

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	Table 6. Dimere 1.5				
	THICKNE (FEET)			THICKNESS (FEET)	DEPTH (FEET)
	Well PT-63-09-203		Clay, hard, yellow	6	39
•	ner: Gulf State Utilities Co.		Clay, yellow, wet	2	41
Own	oriller: Layne-Texas Co.		Clay, hard, yellow	1	42
No record	112	112	Clay, hard, brown, joint	6	48
Clay	5	117	Clay, hard, dark-brown	5	53
Sand	8	125	Clay, dark-blue, sticky	3	56
Clay	4	129	Clay, blue, sandy	1	57
Sand	15	144	Clay, soft blue and shell	1	58
Clay	. 10	154	Clay, soft blue	5	63
Sand	29	183	Clay, dark-gray, sandy and shell	2	65
Clay	31	214	Clay, dark-blue, sticky	6	71
Sand, coarse-grained	36	250	Shells, small, gray	1	72
Shale	124	374	Shells, some large	1	73
Sand	36	410	Clay, dark-gray, sticky	5	78
Shale	80	490	Clay, hard, light-brown	2	80
Sand	52	542	Shells, dark-gray, and medium sized	1	81
Shale	51	593	Clay, hard, brown	1	82
Sand	10	603	Clay, light-brown	3	85
Shale	97	700	Clay, hard, dark-brown	3	88
Sand	14	714	Shale, hard, light-gray,	3	91
Shale	32	746	limy bedded	1	92
Sand	15	761	Clay, black and lignite	8	100
Shale	16	777	Clay, tough, light-blue, sticky	1	101
Sand, water	104	\$ 881	Clay, hard, light-blue	2	103
	47 504		Clay, blue, sandy	1	104
	Well PT-63-17-504		Clay, impervious hard, blue		105
Drille	Owner: W. O. Fawvor er: Works Project Administrati	ion	Sand, dark-gray	1	106
Surface sand, redd		1 1	Clay, compact, hard, brown	1	108
Sand, brown, fine-		6 7	Sand, light-gray, fine-grained	2	112
Sand, brown and s	mall shell		Clay, gray, sandy and small shell	4	115
fragments		1 8	Clay, hard, dark-gray	3	118
Sand, brown, silty and shell fragmen		2 10	Clay, gray, sandy	3	123
Sand, gray, fine-gr		- 45	Clay, hard, dark, impervious	5	123
shell fragments		5 15	Clay, light-gray, sandy and some caliche	2	125
Silt, blue, sandy		1 16	Clay, light-gray and yellow	2	127
Silt, gray, sandy a shell fragments	and small	4 20	with shell and caliche	1	127
Clay, dark-gray, s	ticky	11 31			128
Shell, small, gray,		1 32		1	129
Clay, dark-gray, s pieces of rock		1 33	Clay, gray, with hard pieces of shell and caliche	3	132

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

		KNESS ET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well PT	-63-17-504—Continued	1		Well PT-64-07-2	207	
Clay, hard, light-blue wit shell and caliche	th	3	135	Owner: Lizza Bro Driller: Green B		
w	Vell PT-63-18-101			Clay, green	20	20
-	ner: Houston Oil Co.			Sand, white	10	30
	er: Gust C. Warnecke			Clay, gray	60	90
Mud, black and sand	•	60	60	Clay, blue	25	115
Sand, salt water, no flow	11	15	175	Sand, water	40	155
Clay	27	77	452	Well PT-64-07-4	105	
Sand, flows 7 gallons a m of salt water		1 6	498	Owner: Poley Mit	chell	
Clay and shell mixed		33	1,031	Driller: Green B		
Shell		4	1,035	Sand, red	20	20
Sand, flows salt water		30	1,065	Clay, yellow	60	80
Sans, nons sant motor	•	30	1,000	Clay, blue	50	130
Well PT-64-06-901				Sand, water	25	155
Owner: I. R. Bordages Driller: V. R. Phelps				Well PT-64-14-1	01	
Shale, sandy and clay	2	22	22	Owner: Union Texas Petrolo Driller: Layne-Texa		
Sand, blue	4	16	68	Soil, sandy	2	2
Clay, blue	1	17	85	Clay, yellow	14	16
Clay, yellow		2	87	Sand, fine, loose, white	21	37
Sand, white	3	32	119	Sand, fine, gray, shale	21	58
Shale, blue, chalky	7	75	194	Shale, gray, sandy, with some shell	20	78
Sand, gray, fine-grained		6	200	Shale	35	113
w	/ell PT-64-07-203			Sand, broken, shale (poor)	33	146
	wner: Ivy Senset			Sand, loose, gray (good)	39	185
	riller: Green Bros.			Sand, loose, gray (good)	26	211
Clay, yellow	2	20	20	Shale	11	222
Sand, yellow		5	25	Shale, thin layers	82	304
Clay, yellow	4	10	65			
Clay, blue	7	75	140	Well PT-64-14-4	06	
Sand, salt and pepper	1	6	156	Owner: Union Texas Petrole Driller: Layne-Texa		
w	/ell PT-64-07-204			Surface soil	3	3
Ow	ner: P. A. Neichoy			Clay	38	41
	riller: Green Bros.		20	Sand, fine	7	48
Clay, gray		29	29	Shale	48	96
Sand, red		6	35	Sand	29	125
Clay, blue		55	90	Shale, broken	6	131
Clay, gray		20	110	Sand	30	161
Sand, water	4	15	155			

Table 5.—Drillers' Logs of Wells in Chambers and Jefferson Counties—Continued

	THICKNESS (FEET)	DEPTH (FEET)		THICKNESS (FEET)	DEPTH (FEET)
Well PT-64-14-406-	Continued		Clay, sandy, brown	6	17
••••	7	168	Sand, powder, brown	18	35
Shale, broken	37	205	Clay, white, hard	13	48
Shale	52	257	Clay, blue, hard	7	55
Shale, sandy	15	272	Clay, and shell blue	28	83
Sand	16	288	Clay, brown, hard	8	91
Shale	11	299	Well PT-6	4.15.208	
			Owner: J. J. Heb		
Well PT-64-14			Owner: 3. 3. Het Driller: Gr	een Bros.	
Owner: Union Texas Petro Driller: Layne-Te	oleum Co. Weli 1 exas Co.		Clay, yellow	20	20
Clay	12	12	Sand, white	5	25
Sand, white	35	47	Clay, blue	35	60
Clay, and shale	64	111	Sand, salt and pepper	26	86
Sand, cut clean	80	191	Well PT-6	64-15-603	
Shale	12	203	Owner: S	un Oil Co.	
Sand, good	24	227	Driller: N. I	H. Schnieder	
Sand, coarse	20	247	Clay, yellow	30	30
Shale	28	275	Sand	11	41
Well PT-64-1	5-202		Shale, blue	5	46 61
Owner: C. E.			Sand, fine	15	61 90
Driller: Sun (Oil Co.		Shale, blue	29 9	99
Loam, brown, sandy	4	4	Sand	1	100
Shale, yellow	4	8	Shale, blue		100
Clay, white, and shale	7	15	Well PT-	64-15-705	
Clay, brown	6	21	Owner: F	Pure Oil Co.	
Shale, brown, sandy	12	33		yne-Texas Co. 2	2
Sand, brown	3	36	Topsoil	30	32
Gumbo, blue	38	74	Clay	277	309
Gumbo, blue and yellow with red streaks	23	97	Shale, blue and seashells	163	472
Sand	20	117	Sand, cut good	8	480
			Shale		
Well PT-64-					
Owner: Port Arthu Driller: Pitre W	r Country Club later Wells				
Surface sand, brown	2	2			
Clay, vari-colored, hard	4	6			
Sand, fine, white	5	11			

Table 6.—Water Levels in Wells in Chambers and Jefferson Counties (Water level, in feet, below land surface)

	DATE	WATER LEVEL		DATE	WATER LEVEL		DATE	WATER LEVEL
	Chambers Coun	ty	Nov.	3, 1950	43.24	Oct.	22, 1962	107.57
	Well DH-64-09-3	18	Apr.	19, 1951	48.76	Apr.	2, 1963	105.17
	Owner: Crumpler I	Bros.	Apr.	10, 1952	52.30	Oct.	31	116.28
	Elevation: 55		Oct.	10	52.32	Apr.	6, 1964	112.35
Mar.	31, 1941	50.18	Apr.	13, 1953	63.23	Oct.	14	121.27
Mar.	1, 1948	66.87	Oct.	16	65.76	Apr.	5, 1965	112.39
Oct.	6	67.71	Apr.	15, 1954	65.45	Oct.	18	115.02
Apr.	27, 1949	67.15	Oct.	13, 1955	68.64	Apr.	7, 1966	113.32
Nov.	7	71.85	Apr.	5, 1956	71.83	Oct.	12	117.27
Nov.	3, 1950	77.23	Oct.	13	83.23	Mar.	16, 1967	110.74
Apr.	19, 1951	76.70	Apr.	9, 1957	73.98		=	
Oct.	15	79.00	Oct.	31	73.14		Well DH-64-10	
Apr.	10, 1952	80.29	Apr.	7, 1958	71.40		Owner: C. D. Ha Elevation: 2	
Oct.	10	82.18	Oct.	23	74.21		1939	18
Apr.	13, 1953	83.06	Nov.	10, 1959	90.89	Mar.	5, 1941	18.07
Oct.	16	84.57	Apr.	10, 1961	95.83	Oct.	27, 1948	19.82
Apr.	15, 1954	85.42	Oct.	18	101.6	Nov.	7, 1949	19.66
Oct.	13, 1955	83.07	Oct.	10, 1962	110.0	Apr.	12, 1950	21.22
Apr.	5, 1956	82.52	Apr.	2, 1963	96.0	Nov.	3	21.90
	Well DH-64-09-319		Oct.	28	111.2	Apr.	19, 1951	20.75
	Owner: Crumpler B	tros.	Oct.	18, 1965	85.0		Oct. 15 2	
	Elevation: 55		Mar.	16, 1967	101.9	Apr.	10, 1952	26.15
Mar.	31, 1941	43.16				Oct.	10	22.79
Mar.	1, 1948	61.09		Well DH-64-10	-401	Apr.	13, 1953	22.5
Apr.	10, 1952	79.20		Owner: Fing Furniture Co		Apr.	15, 1954	24.53
Oct.	10	82.91		Elevation: 3	7	Oct.	13, 1955	23.69
Apr.	13, 1953	83.70	Apr.	1955	86		,	
Oct.	16	87.92	Oct.	13	90.99		Well DH-64-10-	501
Apr.	5, 1956	94,19	Apr.	5, 1956	88.34	0	wner: C. T. Jose	
Apr.	9, 1957	79.60	Oct.	18	99.67	July	Elevation: 3	
	Well DH-64-09-90		Apr.	5, 1957	92.26	Oct.	18, 1957 14	70.63
			Oct.	31	97.94			69.55
	Owner: S. R. Willia Elevation: 15	ims	Apr.	7, 1958	94.60	Oct.	31	68.73
Mar.	1, 1948	47.70	Oct.	23	99.38	Apr.	7, 1958	66.10
Oct.	6	46.85	Nov.	9, 1959	101.63	Oct.	23	69.52
Apr.	27, 1949	42.40	Apr.	10, 1961	101.31	Nov.	9, 1959	67.29
Nov.	4	43.18	Oct.	18	103.66	Apr.	10, 1961	63.54
Apr.	12, 1950	47.54	Apr.	6, 1962	106.34	Apr.	6, 1962	65.67
						Apr.	2, 1963	69.69

Table 6.—Water Levels in Wells in Chambers and Jefferson Counties—Continued (Water level, in feet, below land surface)

	DATE	WATER LEVEL	DATE		TER VEL	1	DATE	WATER LEVEL
Well I	DH-64-10-501	Continued	Well	DH-64-11-103		Apr.	6, 1966	17.16
Apr.	7, 1964	40.25		r: Josh Mayes levation: 9		Mar.	15, 1967	17.36
Apr.	5, 1965	43.20	July 15	, 1941 +	6.2		Well DH-64-11-	811
Apr.	7, 1966	40.22	Apr. 24	F	lows	o	wner: G. Chan Elevation: 2	
	Well DH-64-10-	702	Nov. 18	, 1948	4.74	Apr.	1947	12.0
(Owner: Texas Oi	l and	Apr. 28	, 1949	4.44	Oct.	9, 1952	21.86
	Gas Co. Elevation: 32	2	Nov. 8		5.65			
Apr.	19, 1941	43.44	Apr. 10	, 1950	6.48	Apr.	8, 1953	20.54
Oct.	5, 1948	58.40	Nov. 1		7.45	Oct.	15	20.83
Apr.	27, 1949	59.13	Apr. 20	, 1951	8.03	Apr.	14, 1954	21.20
Nov.	3	60.58	Oct. 11		9.11	Oct.	11, 1955	10.58
Apr.	12, 1950	61.25	Apr. 11	, 1952	9.25	Apr.	4, 1956	19.23
Nov.	3	64.80	Oct. 9	1	0.78	Oct.	17	21.48
Apr.	19, 1951	65.70	Apr. 8	, 1953 1	1.21	Apr.	5, 1957	20.11
Oct.	15, 1951	67.80	Oct. 15		2.40	,	Well DH-64-11-	.812
Oct.	13, 1955	82.43	Apr. 14	, 1954 1	3.30		wner: G. Chan	
Oct.	18, 1956	89.75					Elevation: 4	
	1965	106.5	Well	DH-64-11-401		July	24, 1941	4.89
Sept.	1965	106,5		r: E. S. Abshier levation: 5		Oct.	6, 1948	9.08
	Well DH-64-10-	703			0.10	Apr.	28, 1949	5.92
0	wner: V. A. Lav					Nov. 8 7.		7.87
	Elevation: 3			, 1956	9.07	Apr.	10, 1950	7.82
Oct.	1938	38	Oct. 17		10.94	Nov.	1	8.68
Mar.	28, 1941	42.75		i, 1957	9.53	Apr.	20, 1951	6.90
May	7, 1962	89.98	Oct. 30		10.30	Oct.	11	7.84
Oct.	22	96.70	Apr. 10	, 1958	8.42	Apr.	11, 1952	4,14
Apr.	2, 1963	92.26	Oct. 21		9.25			
Oct.	28	99.87	Nov. 9	, 1959	9.03		Well DH-64-11	901
Apr.	6, 1964	94.75	Apr. 7	, 1961	12.67		Owner:Barri	
Oct.	14	103.97	Oct, 19	1	14.77		Elevation: 2	
Apr.	5, 1965	96.24	Apr. 5	i, 1962	15.50	May	2, 1941	6.22
Oct.	18	106.91	Oct. 23	1	16.05	Mar.	16, 1949	12.47
Apr.	7, 1966	98.61	Apr. 4	, 1963	16.61	Aug.	31, 1950	13.34
Oct.	12	104.27	Oct. 30		17.33	Nov.	1	13.74
Mar.	16, 1967	100.47	Apr. 7	7, 1964	16.82	Apr.	20, 1951	14.17
			Oct. 14	. 1	19.02	Oct.	11	14.74
			Apr. 6	3, 1965	16.75	Apr.	11, 1952	14.92
			Oct. 19		18.92	Oct.	9	16.06

Table 6.—Water Levels in Wells in Chambers and Jefferson Counties—Continued (Water level, in feet, below land surface)

	DATE	WATER LEVEL		DATE	WATER LEVEL		DATE	WATER LEVEL
Well	DH-64-11-901C	Continued	Apr.	14, 1954	9.87		Well DH-64-12-	802
Apr. Oct.	8, 1953 15	16.02 16.76	Oct.	11, 1955 4, 1956	9.29 8.52	Owner: U.S. Dept. of Agriculture Elevation: 25		
Apr.	14, 1954	16.97	Oct.	17	9.37	May	2, 1941	5.34
	4, 1956	19.55	Apr.	5, 1957	10.51	Dec.	1, 1948	11.81
Apr.			Oct.	30	9.94	Nov.	8, 1949	12.09
Oct.	17	20.83	Apr.	10, 1958	8.55	Apr.	10, 1950	12.60
Apr.	5, 1957	22.15	Oct.	21	8.87	Nov.	1	13.24
Oct.	30	21.97			8.63			
Apr.	10, 1958	21.32	Nov.	3, 1959		Apr.	20, 1951	13.46
Oct.	21	22.08	Apr.	7, 1961	7.31	Oct.	11	13.90
Nov.	3, 1959	22.86	Apr.	5, 1962	7.27	Apr.	8, 1953	15.16
Apr.	7, 1961	24.39	Apr.	4, 1963	8.51	Oct.	18	15.83
Oct.	19	25.51		Well DH-64-12-401			14, 1954	16.07
Apr.	5, 1962	24.13		Owner: Sun Oil Co.			Well DH-64-13	101
Oct,	23	25,41		Elevation: 2	6		Owner: Oscar De	villier
Apr.	4, 1963	24.77	Apr.	7, 1941	10.84		Elevation: 3	
Oct.	30	25.62	Apr.	14, 1954	17.13	May	16, 1941	6.03
Apr.	7, 1964	25,17	Oct.	11, 1955	18.22	Mar.	15, 1948	6.85
Apr.	6, 1965	25.84	Apr.	4, 1956	18.46	Nov.	8, 1949	5.78
Oct.	19	26.21	Oct.	17	19.56	Apr.	10, 1950	8.15
Apr.	6, 1966	26.34	Apr.	5, 1957	19.32	Nov.	1	8.91
Oct.	13	27.07	Oct.	30	19.84	Apr.	23, 1951	9.05
Mar.	15, 1967	27.15	Apr.	10, 1958	20.43	Oct,	11	9.97
	Well DH-64-12-1	101	Oct.	27	20.92	Apr.	11, 1952	10.86
			Nov.	3, 1959	21.97	Apr.	8, 1953	10.18
	Owner: U.S. Dep Agriculture		Apr.	7, 1961	23.54	Apr.	14, 1954	10.97
	Elevation: 28		Oct.	19	23.42	Apr.	4, 1956	10.73
Apr.	15, 1941	9.35	Apr.	5, 1962	23.49	Oct.	17	11.06
Dec.	1, 1948	8.14	Oct.	23	24.10	Apr.	5, 1957	12.16
Nov.	8, 1949	8.55	Apr.	4, 1963	24.31	Oct.	30	11.03
Apr.	10, 1950	6.49	Oct.	30	24.36	Apr.	10, 1958	12.59
Nov.	1	7.44	Apr.	7, 1964	24.21	Oct.	21	12.71
Apr.	20, 1951	7.66	Oct.	14	24.87	Nov.	3, 1959	13.80
Oct.	11	8.47	Apr.	6, 1965	24.79	Apr.	7, 1961	11.94
Apr.	11, 1952	8.06	Apr.	6, 1966	25.16	Oct.	19	12.03
Oct.	9	8.93				Apr.	5, 1962	12.19
Apr.	8, 1953	8.67				Oct.	23	14.00
Oct.	15	9.65				Apr.	4, 1964	14.01
							.,	

Table 6.—Water Levels in Wells in Chambers and Jefferson Counties—Continued (Water level, in feet, below land surface)

D	ATE	WATER LEVEL	DA		WATER LEVEL	DA	TE	WATER LEVEL
Well Di	H-64-13-101-Co	ntinued	W	ell DH-64-17-60	1	Apr.	12, 1950	97.32
Oct.	30, 1964	15.21	Ov	vner: Asa Wilbur	'n	Nov.	3	100.53
Apr.	6, 1965	14.06		Elevation: 15		Apr.	19, 1951	101.10
Oct.	19	15.73	Apr.	5, 1941	15.88	Apr.	10, 1952	105.52
	6, 1966	14.13	Mar.	1, 1948	14.50	Oct.	10	106.91
Apr. Oct.	5	13.95	Oct.	6	14.48	Apr.	13, 1953	108.83
Oct.	5	10.00	Apr.	27, 1949	14.43	Oct.	16	110.1
,	Well DH-64-17-2	09	Nov.	7	14.75	Apr.	Apr. 15, 1954 109	
o	wner: J. W. Wilb	urn	Apr.	12, 1950	14.67	Oct.	13, 1955	116.85
	Elevation: 16		Nov.	3	14.90	Apr.	5, 1956	116.81
	1931	20	Apr.	19, 1951	15.15	Oct.	18	122.79
Apr.	5, 1941	44.53	Oct.	15	15.18	Apr.	9, 1957	121.96
Aug.	31, 1950	80.60	Apr.	10, 1952	18.24	Oct.	31	124.34
Nov.	3, 1950	80.80	Oct.	10	15.68	Apr.	7, 1958	122.03
	19, 1951	82.01	Apr.	13, 1953	17.96	Oct.	23	125.82
Apr.			Oct.	16	18.49	Nov.	10, 1959	128.36
Oct.	15	85.37	Apr.	15, 1954	16.33	Apr.	10, 1961	130.81
Apr.	10, 1952	85.65	Oct.	13, 1955	18.94	Oct.	18	132.46
Oct.	10	88.59	Apr.	5, 1956	16.97	Apr.	6, 1962	133.16
Apr.	13, 1953	89.73	Oct.	18	21.46	Oct.	22	136.99
Apr.	15, 1954	91.53	Apr.	9, 1957	17.64	Apr.	2, 1963	136.11
			Oct.	31	16.30	Oct.	28	140.21
	Well DH-64-17-		Apr.	7, 1958	15.85	Apr.	6, 1964	139.52
(Owner: The Texa Elevation: 24	es Co. 4	Oct.	23	16.52	Apr.	5, 1965	141.65
May	7, 1962	41.58	Nov.	10, 1959	15.53	Oct.	18	144.84
Oct.	22	43.23	Apr.	10, 1961	16.78	Apr.	7, 1966	144.2
Apr.	2, 1963	41.89	Oct.	18	18.82	Oct.	12	146.5
Oct.	28	45.07	Apr.	6, 1962	17.33	Mar.	16, 1967	147.7
Apr.	6, 1964	41.90	Oct.	22	16.08			
Oct.	14	46.72	Apr.	2, 1963	17.28		Well DH-64-1	7-910
Apr.	5, 1965	42.27	Oct.	28	17.71	0	wner: Charles Elevation:	
Apr.	7, 1966	43.54	Mar.	16, 1967	15.53		1939	55
Oct.	12	44.62				Apr.	9, 1941	59.47
Mar.	16, 1967	43.82		Well DH-64-17		Apr.	1, 1948	88.30
mar.	10, 1307			Owner: Seacrest Elevation: 2		Mar. Oct.	6	95.47
			Oct.	5, 1948	92.60	Aug.	31, 1950	102.70
			Apr.	27, 1949	93.45	Aug. Nov.	31, 1950	102.47
			Nov.	7	97.25		3 19, 1951	104.26
				-		Apr.	19, 1951	.04.20

Table 6.—Water Levels in Wells in Chambers and Jefferson Counties—Continued (Water level, in feet, below land surface)

	DATE	WATER LEVEL		DATE	WATER LEVEL		DATE	WATER LEVEL
Well	DH-64-17-910—0	Continued	Apr.	9, 1963	34.46		Well DH-64-2	0-301
Apr.	10, 1952 13, 1953	108.53 112.16	Apr. June	17, 1964 16, 1965	40.0 39.4		Owner: U.S. D Agricultur Elevation:	re
Oct.	13, 1955	120.45	Aug.	1, 1966	41.41	May	22, 1941	5,54
	Well Du ca ao	•••				Dec.	1, 1948	9.45
	Well DH-64-18-1			Well DH-64-18-		Nov.	8, 1949	8.81
	Owner: W. W. Pfi Elevation: 22		0	wner: Humble (Refining Co		Apr.	10, 1950	9.02
	1928	21		Elevation: 0		Nov.	1	6.06
Mar.	29, 1941	18.91	Apr.	15, 1960	34.69	Apr.	23, 1951	10.89
Oct.	5, 1948	21.38	May	21, 1962	35.74	Oct.	11	10.58
Apr.	27, 1949	19.62	Apr.	9, 1963	37.10	Apr.	11, 1952	10.96
Nov.	4	21.78	June	17, 1964 16, 1965	40.4	Oct.	9	12.38
Apr.	12, 1950	22.17	Aug.	1, 1966	37.9 39.02	Apr.	8, 1953	13.17
Nov.	3	22.75	May	13, 1967	40.6	Oct.	15	11.6
Apr.	19, 1951	22.58	way	15, 1907	40.6	Apr.	4, 1954	11.99
Oct.	15	23.00		Well DH-64-18-	902	Oct.	11, 1955	15.3
Apr.	10, 1952	25.51	Ov	vner: Humble O	il and	Apr.	4, 1956	15.2
Oct.	10	23.92		Refining Co. Elevation: 01	:	Nov.	3, 1959	19.35
Apr.	13, 1953	24.05	May	15, 1942	4.40	Apr.	7, 1961	18.22
Oct,	16	24.84	Dec.	16, 1948	18.15		Well DH-64-22	.402
Apr.	15, 1954	24.33	Aug.	25, 1950	22.91			
Apr.	5, 1956	25.98	May	4, 1951	24.74		Owner: U.S. De Agriculture Elevation: 5	1
	Well DH-64-18-60	01	May	20, 1952	24.95	July	16, 1941	+ 2.9
0	wner: Humble Oil	and	Apr.	16, 1953	27.00	Mar.	15, 1949	+ 0.49
	Refining Co. Elevation: 0		Apr.	29, 1954	28.77	Nov.	9	+ .42
May	29, 1958	32.2	Apr.	24, 1956	35.40	Apr.	11, 1950	+ .41
May	21, 1962	37.90	,	Well DH-64-19-9	04	Nov.	2	+ .46
Apr.	9, 1963	38.35		Owner: R. Barro	ow	Apr.	23, 1951	+ .80
Apr.	17, 1964	39.85		Elevation: 11		Apr.	11, 1952	+ .70
June	16, 1965	40.9	Mar.	1940	Flowed	Oct.	9	11
Aug.	1, 1966	42.3	Nov.	17, 1948	2.84	Oct.	22, 1953	46
May	13, 1967	42.08	Apr.	9, 1949 11, 1950	6.12	Apr.	14, 1954	48
	Well DH-64-18-60	12	Nov.	2	13.94		Well DH-64-26-	704
	vner: Humble Oil	_	Apr.	23, 1951	18.27 19.65		vner: Humble O	
	Refining Co. Elevation: 0±		Oct.	11	19.52	0.	Refining Co. Elevation: 0	ni and
Apr.	15, 1960	32.06				Apr.	14, 1960	68.0
Ma;	21, 1962	34.86				May	21, 1962	69.24

Table 6.—Water Levels in Wells in Chambers and Jefferson Counties—Continued (Water level, in feet, below land surface)

	DATE	WATER LEVEL	D	ATE	WATER LEVEL	D	ATE	WATER LEVEL
Well (DH-64-26-704—C	ontinued	Apr.	5, 1957	6.53	May	16, 1951	4.39
Apr.	9, 1963	69.77	Oct.	30	6.58	May	29, 1952	3.31
Apr.	17, 1964	78.38	Apr.	10, 1958	6.28	May	27, 1953	3.48
June	16, 1965	76.2	Oct.	21	6.64	May	27, 1954	3.98
Aug.	1, 1966	76.75	Nov.	12, 1959	5.51	Dec.	14, 1955	3.57
			Apr.	3, 1962	6.15	May	16, 1956	3.05
	Well DH-64-26-		Oct.	23	6.59	May	29, 1957	3.24
O	wner: Humble O Refining Co.	il and	Apr.	4, 1963	6.36	May	21, 1958	3.48
	Elevation: 0		Oct.	30	6.61	Oct.	19, 1959	2.39
Dec.	16, 1948	59.63	Apr.	7, 1964	6.41	Oct.	11, 1960	3.92
Aug.	25, 1950	58.87	Apr.	6, 1965	6.42	May	10, 1962	3.84
May	4, 1951	58.56	Apr.	6, 1966	6.58	Mar.	20, 1963	10.26
May	20, 1952	61.61	Oct.	13	6.09	Feb.	6, 1964	10.82
May	20	61.79	Mar.	15, 1967	6.56	May	7, 1965	11.09
May	20	61.59						
Apr.	15, 1953	59.96	Jefferson County			1	Well PT-64-06-	401
Apr.	29, 1954	62.47	Well PT-63-01-301			Owr	ner: Texas Pipe Elevation: 2	
Apr.	24, 1956	64.67		Owner: L. J. Gib Elevation: 12		Jan.	28, 1942	+ 1.43
May	29, 1958	70.62	May	18,1950	0.64	May	17, 1951	+ .32
	Well DH-64-27-	201	May 16, 1951 1.47		1.47	June	5, 1952	+ .35
	Owner: Sun Oil		May	29, 1952	3.08	May 27, 1953 -		39
	Elevation: 5		May	27, 1953	3.71	May	28, 1954	+ .01
Apr.	1944	4	May	27, 1954	4.03	Dec.	14, 1955	+ .31
Mar.	17, 1949	4.60	Dec.	14, 1955	7.68	May	16, 1956	+ .28
Nov.	9	22.12	May	28, 1957	9.09	May	29, 1957	+ .46
Apr.	11, 1950	7.22	May	21, 1958	10.57	Nov.	10, 1959	+ .19
Nov.	2	6.34	Oct.	19, 1959	13.54	Oct.	11, 1960	+ .13
Apr.	23, 1951	6.27	Oct.	10, 1960	14.96	May	9, 1962	+ .15
Oct.	11	5.72	May	10, 1962	18.07	Mar.	19, 1963	+ .05
Apr.	11, 1952	6.09	Mar.	19, 1963	20.74	Feb.	6, 1964	+ .13
Oct.	9	6.54	Feb.	6, 1964	22.96	May	7, 1965	.09
Apr.	8, 1953	5.99	Peb.	6, 1504	22.50	Way	7, 1965	.09
Oct.	15, 1953	6.26		Well PT-63-18-	101		Well PT-64-14	406
Apr.	14, 1954	6.82	04	wner: Houston (Elevation: 5			Owner: Union 1 etroleum Co. V Elevation: 1	Veli 9
Apr.	14	6.57		1906	+ 20			
Oct.	11, 1955	6.45	July	18, 1941	+ .72	Aug.	31, 1948	24
			0017	10, 1941				
Apr.	4, 1956	6.39	May	18, 1950	5.52	May May	17, 1951 27, 1953	13.29 31.93

Table 6.—Water Levels in Wells in Chambers and Jefferson Counties—Continued (Water level, in feet, below land surface)

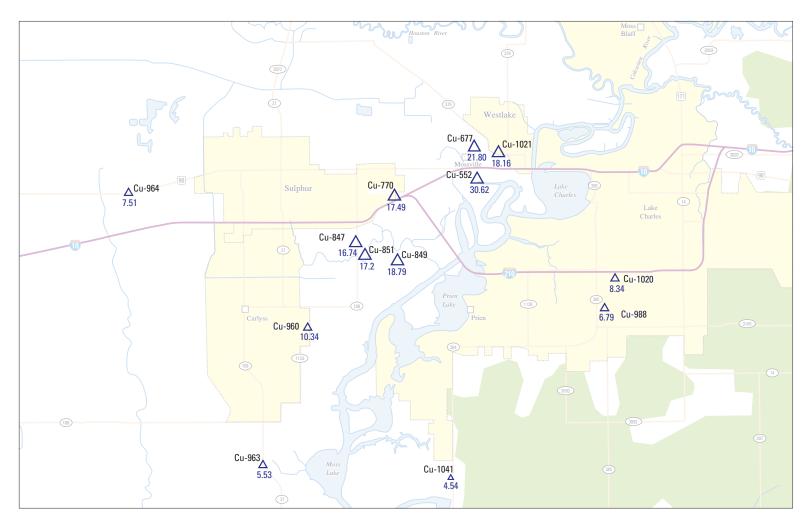
D	ATE	WATER LEVEL		DATE	WATER LEVEL	D	ATE	WATER LEVEL
Well PT	Well PT-64-14-406—Continued		May	16, 1956	7.74	May	28, 1954	2,43
Dec.	14, 1955	36.98	May	29, 1957	9.80	Dec.	14, 1955	3.54
Nov.	4, 1959	45.08	May	21, 1958	9.42	May	16, 1956	3.53
Oct.	11, 1960	47.26	Oct.	19, 1959	7.72	May	29, 1957	4.37
Well PT-64-22-301		Oct.	11, 1960	14.64	May	21, 1958	5.01	
	Owner: Pipkin Ranch		Mar.	20, 1963	10.48	Oct.	19, 1959	4.75
0.	Elevation: 5		May	7, 1965	9.73	Oct.	11, 1960	6.58
May	17, 1951	0.67		Well PT-64-23-1	103	May	10, 1962	7.42
June	5, 1952	2.47				March	20, 1963	8.01
May	22, 1953	6.16		Owner: Pipkin Ranch Elevation: 5			6, 1964	7.82
May	28, 1954	9.99	June	5, 1952	1.06	May	7, 1965	7.69
Dec.	14, 1955	8.91	May	27, 1953	2.67			

WHITE, V.E. AND GRIFFITH, J.M., 2020
POTENTIOMETRIC SURFACES, 2011-12 AND WATER-LEVEL
DIFFERENCES BETWEEN 1995 AND 2011-12 IN WELLS
IN THE "200-FOOT", "500-FOOT", AND "700-FOOT" SANDS OF THE
LAKE CHARLES AREA, SOUTHWESTERN LOUISIANA



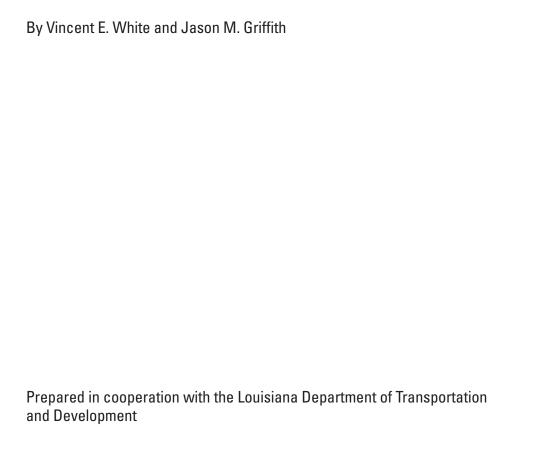
Prepared in cooperation with the Louisiana Department of Transportation and Development

Potentiometric Surfaces, 2011–12, and Water-Level Differences Between 1995 and 2011–12, in Wells of the "200-Foot," "500-Foot," and "700-Foot" Sands of the Lake Charles Area, Southwestern Louisiana



Pamphlet to accompany
Scientific Investigations Map 3460

Potentiometric Surfaces, 2011–12, and Water-Level Differences Between 1995 and 2011–12, in Wells of the "200-Foot," "500-Foot," and "700-Foot" Sands of the Lake Charles Area, Southwestern Louisiana



Scientific Investigations Map 3460

U.S. Department of the Interior DAVID BERNHARDT, Secretary

U.S. Geological Survey James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2020

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit https://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit https://store.usgs.gov.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Suggested citation:

White, V.E., and Griffith, J.M., 2020, Potentiometric surfaces, 2011–12, and water-level differences between 1995 and 2011–12, in wells of the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area, southwestern Louisiana: U.S. Geological Survey Scientific Investigations Map 3460, 4 sheets, 11-p. pamphlet, https://doi.org/10.3133/sim3460.

ISSN 2329-132X (online)

Acknowledgments

The authors gratefully acknowledge the assistance and cooperation of numerous public water suppliers, industrial facilities, and private well owners who allowed water levels to be determined in their wells. Special thanks are given to Zahir "Bo" Bolourchi (retired) and Doug Taylor of the Louisiana Department of Transportation and Development for support and assistance during the preparation of this report and to Brett Rivers, Frank Glass, and Robert Fendick of the U.S. Geological Survey for collecting water-level data for this study.

Contents

Acknowledgments	iii
Abstract	1
Introduction	1
Purpose and Scope	2
Description of Study Area	
Hydrogeologic Setting	2
Methods	3
Potentiometric Surfaces and Water-Level Differences in Wells of the "200-Foot" Sand	7
Potentiometric Surfaces and Water-Level Differences in Wells in the "500-Foot" Sand	9
Potentiometric Surfaces and Water-Level Differences in Wells in the "700-Foot" Sand	9
Summary	10
References Cited	10

Figures

[All sheets available at https://doi.org/10.3133/sim3460]

1.	Map showing study area and hydrogeologic cross-section lines	. Sheet 1
2.	Graphs showing total groundwater withdrawals in Calcasieu and Cameron Parishes, southwestern Louisiana, 1960–2010, and water levels for wells screened in the "200-foot," "500-foot," and "700-foot" sands	. Sheet 1
3.	Hydrogeologic cross sections A–A' and B–B'	. Sheet 1
4.	Graphs showing groundwater withdrawals and water levels from wells screened in the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area in Calcasieu and Cameron Parishes, southwestern Louisiana	. Sheet 1
5.	Map showing potentiometric surface of wells screened in the "200-foot"	
0.	sand of the Lake Charles area and upper and undifferentiated sands of the Chicot aquifer system, southwestern Louisiana, December 2011–March 2012	. Sheet 1
6.	Map showing water-withdrawal sites in the "200-foot" sand of the Lake Charles area and undifferentiated sand and upper sand of the Chicot aquifer system that withdrew at an average rate of at least 0.1 million gallons per day, southwestern Louisiana, 2010	. Sheet 2
7.	Map showing water-withdrawal sites in the "500-foot" sand of the Lake Charles area that withdrew at an average rate of at least 0.1 million gallons per day, southwestern Louisiana, 2010	. Sheet 2
8.	Map showing water-level differences at selected wells in the "200-foot" sand of the Lake Charles area and upper sand of the Chicot aquifer system, southwestern Louisiana, 1995 to 2011–12	. Sheet 2
9.	Map showing potentiometric surface of wells screened in the "500-foot" sand of the Lake Charles area, southwestern Louisiana, December 2011–March 2012	. Sheet 2
10.	Map showing potentiometric surface of wells screened in the "500-foot" sand in the Lake Charles metropolitan area, southwestern Louisiana, December 2011–March 2012	
11.	Map showing water-level differences at selected wells in the "500-foot" sand of the Lake Charles area, southwestern Louisiana, 1995 to 2011–12	
12.	Map showing water-level differences at selected wells in the "500-foot" sand of the Lake Charles metropolitan area, southwestern Louisiana, 1995 to 2011–12	
13.	Map showing potentiometric surface of wells screened in the "700-foot" sand of the Lake Charles area and lower sand of the Chicot aquifer system, southwestern Louisiana, December 2011—March 2012	. Sheet 3
14.	Map showing water-withdrawal sites in the "700-foot" sand of the Lake Charles area and the lower sand of the Chicot aquifer system, southwestern Louisiana, 2010	. Sheet 4
15.	Map showing water-level differences at selected wells in the "700-foot" sand of the Lake Charles area and lower sand of the Chicot aquifer system in the Lake Charles area, southwestern Louisiana, 1995 to 2011–12	

Tables

1.	Water-level data from wells used to prepare the potentiometric surfaces (2011–12) and water-level difference (between 1995 and 2011–12) of the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area, southwestern Louisiana	4
2.	Withdrawals from the "200-foot" sand of the Lake Charles area and upper and undifferentiated sands of the Chicot aquifer system, southwestern Louisiana, 2010	7
3.	Withdrawals from the "500-foot" sand of the Lake Charles area, southwestern Louisiana, 2010	8
4.	Withdrawals, in million gallons per day (Mgal/d), from the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area, southwestern Louisiana, 1994–2012	8
5.	Withdrawals from the "700-foot" sand of the Lake Charles area and lower sand of the Chicot aguifer system, southwestern Louisiana, 2010	9

Conversion Factors

U.S. customary units to International System of Units

Multiply	Ву	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi²)	259.0	hectare (ha)
square mile (mi²)	2.590	square kilometer (km²)
	Flow rate	
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m³/s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: $^{\circ}C = (^{\circ}F - 32) / 1.8$.

Datum

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Altitude, as used in this report, refers to distance relative to the vertical datum.

Supplemental Information

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Abbreviations

DOTD Louisiana Department of Transportation and Development

USGS U.S. Geological Survey

Potentiometric Surfaces, 2011–12, and Water-Level Differences Between 1995 and 2011–12, in Wells of the "200-Foot," "500-Foot," and "700-Foot" Sands of the Lake Charles Area, Southwestern Louisiana

By Vincent E. White and Jason M. Griffith

Abstract

Water levels were determined in 90 wells to prepare 2011–12 potentiometric surfaces focusing primarily on the "200-foot," 500-foot," and "700-foot" sands of the Lake Charles area, which are part of the Chicot aguifer system underlying Calcasieu and Cameron Parishes of southwestern Louisiana. These three aguifers provided 34 percent of the total water withdrawn and 93 percent of the groundwater withdrawn in Calcasieu and Cameron Parishes in 2012 (84.5 million gallons per day [Mgal/d]). This work was completed by the U.S. Geological Survey, in cooperation with the Louisiana Department of Transportation and Development, to assist in developing and evaluating groundwater-resource management strategies. The highest water levels determined in wells screened in the "200-foot," "500-foot," and "700foot" sands were about 8 feet (ft) above the National Geodetic Vertical Datum of 1929 (NGVD 29), 2 ft below NGVD 29, and 14 ft below NGVD 29, respectively, and were located in northwestern Calcasieu Parish. The lowest water levels determined in wells screened in the "200-foot," "500-foot," and "700-foot" sands were approximately 50, 80, and 70 ft below NGVD 29, respectively, and were located in the southern Lake Charles metropolitan area, to the west of Prien Lake, and between the cities of Lake Charles and Sulphur, respectively. The primary groundwater flow direction in these three aquifers was radially towards pumping centers overlying the water-level lows. Comparisons of water-level differences in 42 wells measured in 1995 and 2011-12 indicated that the maximum increases in water levels for wells screened in the "200-foot," "500-foot," and "700-foot" sands were approximately 7, 31, and 19 ft, respectively. Waterlevel increases coincided with a decline in total groundwater withdrawals during the period (about 25 Mgal/d from 1995 to 2012) from these sands. More specifically, withdrawals from the "500-foot" sand affected water levels in wells screened in the "200-foot" and "700-foot" sands because the three are hydraulically connected and withdrawals from the "500-foot" sand were greater by volume than withdrawals from the "200foot" and "700-foot" sands.

Introduction

Increases in groundwater withdrawals can lead to declining water levels and changes in flow directions and can affect water quality. Withdrawals from the Chicot aquifer system in the Lake Charles area of southwestern Louisiana (fig. 1), primarily from the "500-foot" sand, have caused long-term (years to decades) potentiometric-surface declines resulting in a cone of depression in the "500-foot" sand that extends across Calcasieu Parish. Because the "200-foot" and "700-foot" sands are hydraulically connected to the "500-foot" sand in this area, withdrawals from the "500-foot" sand have lowered water levels in wells screened in the "200-foot" and "700-foot" sands (figs. 2–4). Withdrawals have also caused hydraulic gradients favorable for encroachment of saltwater¹ towards fresh groundwater in the Lake Charles area (Lovelace, 1999).

Additional knowledge about groundwater levels, groundwater flow, and the effects of withdrawals on the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area is needed to assess the effects of withdrawals, determine the direction of groundwater flow, and develop sustainable groundwater-resource management strategies. To meet this need, the U.S. Geological Survey (USGS), in cooperation with the Louisiana Department of Transportation and Development (DOTD), began a study in 2011 to measure depth to water in a network of 90 wells in order to determine and document water levels in wells screened in the "200-foot," "500-foot," and "700-foot" sands and to prepare potentiometric surfaces and evaluate differences in water levels.

^{&#}x27;Saltwater in this report is defined as water that contains chloride at concentrations of more than 250 milligrams per liter (mg/L). Concentrations of chloride less than 250 mg/L are within the secondary maximum contaminant level (SMCL) and are considered freshwater. The SMCLs are Federal guidelines regarding cosmetic effects (such as tooth or skin discoloration), aesthetic effects (such as taste, odor, or color), or technical effects (such as damage to water equipment or reduced effectiveness of treatment for other contaminants) of potential constituents of drinking water. The SMCLs were established as guidelines by the U.S. Environmental Protection Agency (2016).

Purpose and Scope

This report presents data, analysis, and maps that primarily describe the potentiometric surfaces of the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area during 2011–12. Water-level differences are calculated for select wells measured in both 1995 and 2011–12. In addition to the data presented in this report, water-level data are also available from the USGS National Water Information System database (U.S. Geological Survey, 2017a) and Louisiana Water-Use Program (U.S. Geological Survey, 2017b).

Description of Study Area

The study area (fig. 1) extends across about 2,300 square miles and includes all of Calcasieu Parish, the western twothirds of Cameron Parish, and the extreme southwestern corner of Jefferson Davis Parish in southwestern Louisiana. The largest city in the study area, Lake Charles, had a 2010 population of about 72,000 (U.S. Census Bureau, 2019). Much of the study area is rural and agricultural, with rice production being a historically important agricultural sector (Louisiana State University AgCenter, 2015; fig. 1). Many and various industrial facilities are located near the Lake Charles metropolitan area, in the vicinity of the western bank of the Calcasieu River, and in Westlake. The climate is generally warm and temperate with high humidity and frequent rainfall. For the city of Lake Charles, the average annual temperature is 68 degrees Fahrenheit, and the average annual rainfall is about 56 inches (National Oceanic and Atmospheric Administration, 2011). Topographically, the study area is composed of a coastal plain, with the highest surface altitudes at about 90 feet (ft) above the National Geodetic Vertical Datum of 1929 (NGVD 29) at the northern border of the study area near DeQuincy and the lowest altitudes equivalent to about NGVD 29 at the southern border of the study area (U.S. Geological Survey, 2015).

Hydrogeologic Setting

The Chicot aquifer system underlies southwestern Louisiana and parts of southeastern Texas and is composed of a sequence of deposits of silt, sand, and gravel interbedded with clay and sandy clay that dips and thickens towards the south and southeast (fig. 3) (Nyman, 1984). The sand

deposits grade southward from coarse sand and gravel to finer sediments and become increasingly subdivided by clay layers. A surficial clay confining layer overlies most of the Chicot aquifer system in southwestern Louisiana. Underlying the study area, the Chicot aquifer system is composed of various aquifers including the "200-foot," "500-foot," and "700-foot" sands, the upper and lower sands, and the undifferentiated sand (figs. 1 and 3). In addition, various shallow sands are present within a surficial confining layer (Lovelace, 1999).

The "200-foot," "500-foot," and "700-foot" sands are named for their general depths of occurrence in the Lake Charles area (Jones, 1950) and are located beneath central and western Calcasieu and Cameron Parishes (fig. 1) (Lovelace, 1998). Along the northern border of Calcasieu Parish, these sands merge into a single massive undifferentiated sand unit. The upper and lower sand units are in the eastern parts of Calcasieu and Cameron Parishes and are stratigraphically equivalent and hydraulically connected to the "200-foot" and the "700-foot" sands, respectively, in the Lake Charles area. Although the "500-foot" sand is stratigraphically equivalent to the lower sand unit of the Chicot aquifer system, it generally pinches out (disappears) to the east where it is commonly not directly hydraulically connected with the lower sand unit of the Chicot aquifer system (Lovelace, 1999).

Recharge to the Chicot aquifer system results from infiltration of precipitation primarily north of the study area (fig. 1 index map), where the aquifer system is at or near ground surface. In the recharge area, water percolates down into and through sandy surficial soil eventually reaching the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area (Nyman and others, 1990; Lovelace and others, 2001). Additional recharge is from leakage through vertically adjacent clay confining units (fig. 3).

Prior to extensive groundwater development in the study area during the 1940s, the movement of groundwater in the Chicot aquifer system as a whole was generally downgradient from north to south, and groundwater discharged into shallower aquifers or to the surface along the Sabine River and the Gulf of Mexico (Nyman and others, 1990). Since the 1940s, large withdrawals for industrial use, agriculture, and public supply primarily from the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area have caused water-level declines and altered the flow of groundwater in the study area. These declines have resulted in groundwater flowing towards the concentrated pumping in the vicinity of Lake Charles in Calcasieu Parish and towards agricultural areas (fig. 1) (Jones and others, 1954; Lovelace, 1998).

Methods

Potentiometric-surface maps were prepared based on water levels determined from 90 wells screened primarily in the "200-foot," "500-foot," and "700-foot" sands (table 1). Water levels were calculated by subtracting the depth-to-water measurement from the land-surface altitude and are referenced to NGVD 29. Seven nearby wells (Cu-971, Cu-5866Z, JD-485A, Cu-11708Z, Cu-10260Z, Cu-970, and Cu-1269) that were not screened in the "200-foot," "500-foot," and "700-foot" sands, but which were screened in hydraulically connected and stratigraphically equivalent sands (upper sand, lower sand, and undifferentiated sand) were used to create more complete potentiometric surfaces and water-level difference maps. Although used to present a more complete potentiometric surface, well Cu-11708Z was not used for analysis of minimum and maximum water levels because this well is screened in the undifferentiated sand in the northern part of the study area, where the "200-foot," "500-foot," and "700-foot" sands have merged. Cu-10260Z is coded as screened in the undifferentiated sand but is south of the approximate boundary between the undifferentiated sand and "200-foot" sand (fig. 1) and was treated accordingly.

Depth to water in each well was measured by using a steel or electrical tape marked with 0.01-ft gradations and were reported to one-hundredths of a foot, following procedures in Cunningham and Schalk (2011). Wells in which depth to water was measured were not being pumped at the time the measurements were made. If wells had been recently pumped, depth to water was measured after an appropriate recovery period. Water-level data were collected from December 2011 through March 2012; water levels in the study area typically decline (because of seasonal withdrawals) to their yearly low in June. Potentiometric contours were drawn as approximate around individual wells if the water levels differed appreciably from water levels in nearby wells or if data were sparse. Water levels determined during 1995 and 2011–12 at selected wells (table 1) were used to prepare waterlevel difference maps. When more than one measurement had been made at a selected well during those years, measurements made during the same time of year were preferentially chosen to minimize potential differences resulting from seasonal water-level fluctuations; however, same-season measurements were not always available.

Water-withdrawal data are collected collaboratively between the Louisiana DOTD and the USGS and made possible by the USGS Water Resources Cooperative Program: Louisiana Water-Use Program (U.S. Geological Survey, 2017b). Through this program, water-withdrawal data are collected from users or determined indirectly based on population size, agricultural-use types, and water-use coefficients. Totals are analyzed, compiled, and published by USGS on behalf of the Louisiana DOTD (U.S. Geological Survey, 2017b). Withdrawal data are provided to the public in several different combinations, such as by parish and aquifer, by State and aquifer, and by groundwater and parish; however, certain combinations and information are not published. Data that would reveal the exact location, such as address or latitude-longitude of withdrawal points, are not published in order to protect proprietary information. In addition, withdrawal data for individual sands within a larger aquifer or aquifer system are not published. For the purposes of this report, water use from each sand, the "200-foot," 500foot," and "700-foot" sands, are disaggregated from the total withdrawal values from the Chicot aguifer. This facilitates a clearer understanding of the effects of withdrawals on the water-level altitude surfaces for each respective sand unit. For further information, contact either the Louisiana Water-Use Program USGS Lower Mississippi-Gulf Water Science Center, Baton Rouge office or the Louisiana DOTD Water Supply Availability and Use Program (Louisiana Department of Transportation and Development, 2018).

As with water-level data, withdrawal maps for the "200foot," "500-foot," and "700-foot" sands included withdrawals from the relevant upper, lower, and undifferentiated sands of the Chicot aguifer system. In this report, the withdrawal maps only included values that were greater than an average of 0.1 million gallons per day (Mgal/d) at an individual well or a group of closely located wells. These values were provided to the Louisiana Water-Use Program and did not include indirectly determined values. Historical totals for groundwater withdrawals in the study area for 1960-2010 included the total groundwater withdrawals from all groundwater sources for Calcasieu and Cameron Parishes and have been provided to enable the reader to see current water-use values in their historical context. Historical totals for groundwater withdrawals in the study area for 1995–2012 included only withdrawals from the "200-foot," "500-foot," and "700-foot" sands.

Table 1. Water-level data from wells used to prepare the potentiometric surfaces (2011–12) and water-level difference (between 1995 and 2011–12) of the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area, southwestern Louisiana.

[USGS, U.S. Geological Survey; NGVD 29, National Geodetic Vertical Datum of 1929; mm, month; dd, day; yyyy, year; –, measurement not available during relevant time period; *, indicates that the well is screened in either the upper, lower, or undifferentiated sands of the Chicot aquifer system]

Well site name	USGS site number	Altitude of land surface, in feet above NGVD 29	Well depth, in feet below land surface	Date measured, mm/dd/yyyy	Depth to water level, in feet below land surface	Water-level altitude, in feet above or below (-) NGVD 29	Date measured, mm/dd/yyyy	Depth to water level, in feet below land surface	Water-level altitude, in feet above or below (-) NGVD 29	Difference, in feet between 1995 and 2011–12 value
				4.	'200-foot" sand					
					2011–12			1995		
Cu- 529	300818093361601	18	276	12/30/2011	51.88	-33.88	12/7/1995	53.91	-35.91	2.03
Cu- 768	301036093124402	11.53	306	12/15/2011	61.42	-49.89	_	_	_	_
Cu- 771	301336093183002	17.76	241	12/16/2011	55.40	-37.64	10/12/1995	60.73	-42.97	5.33
Cu- 798	300919093055601	25.43	345	3/7/2012	59.08	-33.65	_	_	_	_
Cu- 843	301148093193202	12	205	2/20/2012	48.23	-36.23	2/13/1995	51.74	-39.74	3.51
Cu- 946	301356093171001	15	198	3/6/2012	54.25	-39.25	9/28/1995	61.68	-46.68	7.43
Cu- 962	300812093165801	11	287	12/19/2011	48.60	-37.60	_	_	_	_
Cu- 975	301941093035602	20	237	12/21/2011	37.83	-17.83	11/29/1995	37.20	-17.20	-0.63
Cu- 984	300406093070001	15	325	3/7/2012	46.20	-31.20	_	_	_	_
Cu- 990	301059093125103	14	183	12/15/2011	57.73	-43.73	11/2/1995	60.68	-46.68	2.95
Cu-1101	301157093250501	12	260	2/14/2012	58.33	-46.33	_	_	_	_
Cu-11429Z	300545093163101	7	255	3/7/2012	40.35	-33.35	_	_	_	_
Cu-11872Z	301416093153501	11	202	2/21/2012	47.19	-36.19	_	_	_	_
Cu-12305Z	301445093164601	12	155	3/6/2012	43.51	-31.51	_	_	_	_
Cu-12600Z	300836093281801	11	280	12/29/2011	35.79	-24.79	_	_	_	_
Cu-12284Z	301016093224101	16	250	3/7/2012	51.11	-35.11	_	_	_	_
Cu-12933Z	301725093224101	22	110	3/7/2012	23.46	-1.46	_	_	_	_
Cu-1332	301033093205402	16	240	1/5/2012	58.69	-42.69	_	_	_	_
Cu-13320Z	301709093334401	27	280	2/21/2012	44.42	-17.42	_	_	_	_
Cu-13362Z	301201093404201	12	280	12/30/2011	34.02	-22.02	_	_	_	_
Cu-13571Z	301703093090501	13	180	3/5/2012	37.69	-24.69	_	_	_	_
Cu-6750Z	301512093171501	16	150	3/6/2012	48.71	-32.71	_	_	-	_
Cu-9584Z	301335093344401	23	280	1/12/2012	47.49	-24.49	_	_	-	_
Cn- 90	295611093044801	3.19	396	3/6/2012	31.62	-28.43	4/11/1995	23.92	-20.73	-7.70
Cn- 92	300104093015601	5.5	443	12/21/2011	38.99	-33.49	4/11/1995	29.66	-24.16	-9.33
Cu- 971*	300534092564402	5	500	12/22/2011	42.63	-37.63	11/21/1995	39.93	-34.93	-2.70
Cu-5866Z*	301118093004801	24	265	1/3/2012	61.22	-37.22	-	_	-	-
JD- 485A*	301300092584503	21	290	2/7/2012	57.57	-36.57	2/14/1995	50.95	-29.95	-6.62
Cu-11708Z*	302828093265801	88	260	1/10/2012	69.08	18.92	-	_	-	-
Cu-10260Z*	302059093402001	34	220	2/21/2012	26.36	7.64	_	_	_	_

Table 1. Water-level data from wells used to prepare the potentiometric surfaces (2011–12) and water-level difference (between 1995 and 2011–12) of the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area, southwestern Louisiana.—Continued

[USGS, U.S. Geological Survey; NGVD 29, National Geodetic Vertical Datum of 1929; mm, month; dd, day; yyyy, year; –, measurement not available during relevant time period; *, indicates that the well is screened in either the upper, lower, or undifferentiated sands of the Chicot aquifer system]

Well site name	USGS site number	Altitude of land surface, in feet above NGVD 29	Well depth, in feet below land surface	Date measured, mm/dd/yyyy	Depth to water level, in feet below land surface	Water-level altitude, in feet above or below (-) NGVD 29	Date measured, mm/dd/yyyy	Depth to water level, in feet below land surface	Water-level altitude, in feet above or below (-) NGVD 29	Difference, in feet between 1995 and 2011–12 value
				11	500-foot" sand					
					2011–12			1995		
Cu- 463B	301106093203202	17	516	1/5/2012	89.59	-72.59	_	_	_	_
Cu- 552	301359093162202	13	517	1/11/2012	85.63	-72.63	9/6/1995	116.25	-103.25	30.62
Cu- 677	301445093162201	10	568	3/6/2012	77.89	-67.89	9/20/1995	99.69	-89.69	21.80
Cu- 770	301336093183003	17.54	490	12/16/2011	85.05	-67.51	10/12/1995	102.54	-85.00	17.49
Cu-787	300353093210201	4.33	734	3/28/2012	48.60	-44.27	4/11/1995	50.59	-46.26	1.99
Cu- 828	301149093190801	10	560	1/5/2012	89.64	-79.64	_	_	_	_
Cu- 847	301230093193202	13	522	12/16/2011	81.87	-68.87	10/12/1995	98.61	-85.61	16.74
Cu- 849	301205093182501	10	564	1/4/2012	79.20	-69.20	10/11/1995	97.99	-87.99	18.79
Cu- 851	301213093191701	10	555	12/21/2011	80.75	-70.75	5/24/1995	97.9	-87.9	17.2
Cu- 895	301707093211601	18	355	12/13/2011	62.36	-44.36	_	_	_	_
Cu- 947	300643093044701	20	600	12/15/2011	59.78	-39.78	11/29/1995	58.89	-38.89	-0.89
Cu- 957	301120093191002	17	500	1/5/2012	90.37	-73.37				
Cu- 960	301031093204902	21	598	12/16/2011	85.48	-64.48	10/11/1995	95.82	-74.82	10.34
Cu- 961	301214093223201	14	540	2/20/2012	55.86	-41.86	_	_	_	_
Cu- 963	300718093220001	10	399	12/29/2011	61.53	-51.53	12/7/1995	67.06	-57.06	5.53
Cu- 964	301339093253901	16	360	12/29/2011	56.43	-40.43	11/22/1995	63.94	-47.94	7.51
Cu- 977	301944093170402	20	515	12/20/2011	47.83	-27.83	11/22/1995	54.44	-34.44	6.61
Cu- 988	301059093125101	14	523	12/15/2011	74.69	-60.69	11/2/1995	81.48	-67.48	6.79
Cu-1018	301800093121701	20	398	12/13/2011	54.47	-34.47	_	_	_	_
Cu-1019	300354093205501	5	700	3/6/2012	53.84	-48.84	_	_	_	_
Cu-1020	301141093123501	18	375	12/15/2011	77.68	-59.68	11/2/1995	86.02	-68.02	8.34
Cu-1021	301435093154601	12	487	12/19/2011	75.27	-63.27	10/12/1995	93.43	-81.43	18.16
Cu-1041	300702093165801	9	560	12/15/2011	65.18	-56.18	11/2/1995	69.72	-60.72	4.54
Cu-1051	301401093302401	20	410	2/2/2012	53.23	-33.23	12/13/1995	57.42	-37.42	4.19
Cu-1055	301450093251501	15	520	2/2/2012	55.27	-40.27	_	-	_	-
Cu-11500Z	302127093102801	34	250	12/14/2011	54.97	-20.97	_	_	_	-
Cu-1160	301559093374601	25	526	2/1/2012	46.50	-21.50	_	-	_	-
Cu-11708Z*	302828093265801	88	260	1/10/2012	69.08	18.92	_	_	_	-
Cu-12287Z	300822093321201	10	460	2/2/2012	43.44	-33.44	_	-	_	-
Cu-12469Z	301753093300501	26	250	2/1/2012	59.47	-33.47	_	-	-	-
Cu-12489Z	301401093063201	17	460	12/14/2011	56.77	-39.77	_	_	_	_

Table 1. Water-level data from wells used to prepare the potentiometric surfaces (2011–12) and water-level difference (between 1995 and 2011–12) of the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area, southwestern Louisiana.—Continued

[USGS, U.S. Geological Survey; NGVD 29, National Geodetic Vertical Datum of 1929; mm, month; dd, day; yyyy, year; –, measurement not available during relevant time period; *, indicates that the well is screened in either the upper, lower, or undifferentiated sands of the Chicot aquifer system]

Well site name	USGS site number	Altitude of land surface, in feet above NGVD 29	Well depth, in feet below land surface	Date measured, mm/dd/yyyy	Depth to water level, in feet below land surface	Water-level altitude, in feet above or below (-) NGVD 29	Date measured, mm/dd/yyyy	Depth to water level, in feet below land surface	Water-level altitude, in feet above or below (-) NGVD 29	Difference, in feet between 1995 and 2011–12 value
					ot" sand—Contin					
					2011–12—Continu			1995		
Cu-1267	301852093393901	30	405	12/14/2011	32.43	-2.43	_	-	-	-
Cu-1319	301359093160701	15	510	1/11/2012	85.35	-70.35	_	_	-	-
Cu-1328	301420093130301	16	495	3/8/2012	79.70	-63.70	_	-	-	-
Cu-13524Z	301031093255301	10	470	2/20/2012	54.23	-44.23	_	_	-	_
Cu-13585Z	301628093073601	15	300	12/14/2011	44.49	-29.49	_	-	-	-
Cn- 87	295324093240602	8.46	804	3/6/2012	44.26	-35.80	_	_	-	-
Cn- 88L	300055093093004	8.86	804	12/15/2011	48.49	-39.63	4/11/1995	45.49	-36.63	-3.00
Cn- 120	295721093115701	3	764	3/6/2012	37.50	-34.50	_	_	-	-
Cn- 134	295839093203501	5	710	3/6/2012	43.16	-38.16	_	_	_	
					700-foot" sand					
					2011–12			1995		
Cu- 746	301300093161601	4.09	780	1/11/2012	70.16	-66.07	10/20/1995	89.51	-85.42	19.35
Cu- 767	301036093124401	11.42	850	12/15/2011	68.31	-56.89	4/10/1995	69.46	-58.04	1.15
Cu- 769	301336093183001	17.62	642	12/16/2011	84.85	-67.23	4/10/1995	97.52	-79.90	12.67
Cu- 788	300825093260801	6.11	805	12/19/2011	52.37	-46.26	11/22/1995	54.67	-48.56	2.30
Cu- 811	300812093165802	11	923	12/19/2011	65.71	-54.71	_	_	_	-
Cu- 958	301944093170401	20	707	12/20/2011	46.23	-26.23	11/30/1995	52.55	-32.55	6.32
Cu- 959	301031093204901	21	733	12/16/2011	82.22	-61.22	10/11/1995	92.01	-71.01	9.79
Cu- 972	301941093035601	20	595	12/21/2011	43.27	-23.27	11/29/1995	42.38	-22.38	-0.89
Cu- 978	301409093120301	15	645	12/20/2011	68.14	-53.14	11/1/1995	77.24	-62.24	9.10
Cu- 994	300634093400401	5	757	12/20/2011	40.77	-35.77	12/8/1995	33.00	-28.00	-7.77
Cu-1022	301444093162901	11	618	1/4/2012	77.48	-66.48	9/28/1995	95.78	-84.78	18.30
Cu-11708Z*	302828093265801	88	260	1/10/2012	69.08	18.92	_	_	_	-
Cu-1239	302106093115401	25	502	3/5/2012	47.83	-22.83	11/30/1995	54.08	-29.08	6.25
Cu-12894Z	300404093115801	10	520	2/20/2012	50.91	-40.91	_	_	_	-
Cu-1388	301852093393902	30	585	12/30/2011	44.13	-14.13	12/12/1995	44.50	-14.50	0.37
Cu-1419	301331093172801	12	620	3/6/2012	81.59	-69.59	-	_	-	-
Cn- 94	294543093391401	6.22	1,118	3/6/2012	37.98	-31.76	_	_	_	-
Cn- 119	294709093174302	3.5	910	3/6/2012	25.62	-22.12	-	-	-	-
Cu- 970*	300534092564401	5	780	12/22/2011	43.33	-38.33	11/21/1995	40.19	-35.19	-3.14
¹ Cu-1269*	301414093004501	22	503	1/3/2012	86.60	-64.60	12/12/1995	63.84	-41.84	-22.76

¹Nearby site that taps the same aquifer was being pumped for both the 1995 and 2011–12 values.

Potentiometric Surfaces and Water-Level Differences in Wells of the "200-Foot" Sand

Water levels in the "200-foot" sand generally were highest in northern Calcasieu Parish and lowest in the southern part of the city of Lake Charles; the highest water level was 7.64 ft above NGVD 29 at well Cu-10260Z (table 1; fig. 5),² and the lowest water level was 49.89 ft below NGVD 29 at well Cu-768 (fig. 5). The direction of groundwater flow in much of the aquifer was generally from north to south and radially towards a shallow cone of depression delineated by the -40-ft contour on figure 5. Although there are waterwithdrawal sites in the "200-foot" sand in the vicinity of the cone of depression (fig. 6; table 2), the cone is primarily the result of much heavier pumping in this same area from

the "500-foot" sand (fig. 7; table 3), which is hydraulically connected to and affects water levels in wells screened in the "200-foot" sand as can be seen in the historical water use and water levels in the "200-foot," "500-foot," and "700-foot" sands (fig. 4; table 4).

Water-level differences in wells screened primarily in the "200-foot" sand indicate increases of as much as 7.4 ft at wells in the Lake Charles metropolitan area and in western Calcasieu Parish (fig. 8; table 1) from 1995 to 2011, whereas water levels declined as much as 9 ft at wells near the eastern border of the study area during the same period. The water-level increases were primarily the result of reduced withdrawals from the "500-foot" sand; withdrawals from the "200-foot" sand changed little from 1995 to 2011–12 (fig. 4). The water-level declines along the eastern border of the study area could be the result of seasonal fluctuations or increased withdrawals from the Chicot aquifer upper sand in neighboring Jefferson Davis Parish, where groundwater withdrawals increased from 66.03 Mgal/d in 1995 to 90.18 Mgal/d in 2012 (U.S. Geological Survey, 2017b).

Table 2. Withdrawals from the "200-foot" sand of the Lake Charles area and upper and undifferentiated sands of the Chicot aguifer system, southwestern Louisiana, 2010.

Site number¹	Parish	Withdrawal rate, in million gallons per day (Mgal/d)	Aquifer	
A2	Calcasieu	0.6	undifferentiated sand	
B2	Calcasieu	0.5	"200-foot" sand	
C2	Calcasieu	0.1	"200-foot" sand	
D2	Calcasieu	1.0	"200-foot" sand	
E2	Calcasieu	0.3	"200-foot" sand	
F2	Calcasieu	0.1	"200-foot" sand	
G2	Calcasieu	0.1	"200-foot" sand	
H2	Cameron	0.2	"200-foot" sand	
I2	Cameron	0.2	"200-foot" sand	
J2	Cameron	0.1	upper sand	
K2	Cameron	0.4	upper sand	

¹See figure 6.

²As mentioned previously in Methods, well Cu-11708Z was not included in the max-min analysis.

Table 3. Withdrawals from the "500-foot" sand of the Lake Charles area, southwestern Louisiana, 2010.

Site number¹	Parish	Withdrawal rate, in million gallons per day (Mgal/d)	Aquifer
A5	Calcasieu	2.3	"500-foot" sand
B5	Calcasieu	0.6	"500-foot" sand
C5	Calcasieu	1.5	"500-foot" sand
D5	Calcasieu	2.8	"500-foot" sand
E5	Calcasieu	6.5	"500-foot" sand
F5	Calcasieu	1.6	"500-foot" sand
G5	Calcasieu	1.5	"500-foot" sand
Н5	Calcasieu	0.4	"500-foot" sand
15	Calcasieu	20.7	"500-foot" sand
J5	Calcasieu	0.7	"500-foot" sand
K5	Calcasieu	0.5	"500-foot" sand
L5	Calcasieu	1.0	"500-foot" sand
M5	Calcasieu	1.4	"500-foot" sand
N5	Calcasieu	0.1	"500-foot" sand
O5	Calcasieu	9.7	"500-foot" sand
P5	Calcasieu	11.6	"500-foot" sand
Q5	Calcasieu	2.5	"500-foot" sand
R5	Calcasieu	1.7	"500-foot" sand
S5	Calcasieu	0.4	"500-foot" sand
T5	Cameron	0.1	"500-foot" sand
U5	Cameron	0.2	"500-foot" sand
V5	Cameron	0.2	"500-foot" sand
W5	Cameron	0.2	"500-foot" sand

¹See figure 7.

Table 4. Withdrawals, in million gallons per day (Mgal/d), from the "200-foot," "500-foot," and "700-foot" sands of the Lake Charles area, southwestern Louisiana, 1994–2012.

Year	"200-foot" sand (Mgal/d)	"500-foot" sand (Mgal/d)	"700-foot" sand (Mgal/d)	Total (Mgal/d)
1995	9.18	90.37	9.82	109.36
2000	19.45	95.74	9.79	124.97
2005	11.76	71.11	4.81	87.68
2010	9.68	72.38	3.22	85.28
2012	9.34	71.93	3.24	84.51

Potentiometric Surfaces and Water-Level Differences in Wells in the "500-Foot" Sand

Water levels in the "500-foot" sand generally were highest in northern Calcasieu Parish and lowest between Carlyss and Prien. The highest of the 40 water levels determined in wells screened in the "500-foot" sand was 2.43 ft below NGVD 29 at well Cu-1267 in northwestern Calcasieu Parish (fig. 9).3 The lowest water level in the "500foot" sand, 79.64 ft below NGVD 29, was determined at well Cu-828, located about 2 miles west-northwest of Prien Lake (fig. 10). Water levels were more than 40 ft below NGVD 29 in most of the Lake Charles metropolitan area. A large cone of depression centered on the area between Lake Charles and Prien Lake comprises two smaller cones of depression underlying major pumping centers (fig. 7), where water levels were 70-80 ft below NGVD 29. The general direction of flow in the "500-foot" sand during 2011-12 was radially towards these pumping centers.

Water-level differences at wells screened in the "500-foot" sand indicate increases of as much as 6.6 ft outside of the Lake Charles metropolitan area, with minor decreases at two wells located southeast of the metropolitan area (fig. 11). In the metropolitan area, water-level increases were more substantial, rising over 30 ft (fig. 12). The water-level increases in wells screened in the metropolitan area resulted from reduced withdrawals from the "500-foot" sand, which declined from 90.37 Mgal/d in 1995 to 71.93 Mgal/d in 2012 (fig. 4; table 4).

Water levels in the "700-foot" sand generally were highest in northern Calcasieu Parish and lowest near the Calcasieu River north of Prien. The highest water level was 14.13 ft below NGVD 29 at well Cu-1388 (fig. 13; table 1),⁴ and the lowest water level was 69.59 ft below NGVD 29 at well Cu-1419. The potentiometric surface was more than 50 ft below NGVD 29 in most of the Lake Charles metropolitan area. The direction of groundwater flow in much of the aquifer was generally radial towards the cone of depression underlying the metropolitan area (fig. 13). Comparatively, there was little pumping from the "700-foot" sand or lower sand within the cone of depression (fig. 14; table 5), and the cone is the result of heavier pumping from the "500-foot" sand (fig. 7; table 3), which is hydraulically connected to and affects water levels in the "700-foot" sand.

Water-level differences at wells screened primarily in the "700-foot" sand of the Lake Charles area indicate increases of about 19 ft in the north-central part of the study area; however, water levels decreased at wells near the eastern edge of the study area and in southwestern Calcasieu Parish (fig. 15). Although withdrawals from the "700-foot" sand decreased from 9.82 Mgal/d in 1995 to 3.24 Mgal/d in 2012 (fig. 4), the water-level increases were primarily the result of reduced withdrawals from the "500-foot" sand. The large water-level decline at well Cu-1269 at the town of Iowa (fig. 15) was probably the result of pumping at a nearby well when the 2011 water level was determined and not indicative of broader declines in the aquifer in that area. The other declines near the eastern border were relatively small and could have resulted from seasonal water-level variation. The cause of the 7.77-ft decline in southwestern Calcasieu Parish is undetermined.

Table 5. Withdrawals from the "700-foot" sand of the Lake Charles area and lower sand of the Chicot aguifer system, southwestern Louisiana, 2010.

Site number ¹	Parish	Withdrawal rate, in million gallons per day (Mgal/d)	Aquifer	
A7	Calcasieu	0.9	"700-foot" sand	
B7	Calcasieu	1.0	"700-foot" sand	
C7	Calcasieu	0.3	lower sand	

¹See figure 14.

Potentiometric Surfaces and Water-Level Differences in Wells in the "700-Foot" Sand

 $^{^3}$ As mentioned previously in *Methods*, well Cu-11708Z was not included in the max-min analysis.

 $^{^4}$ As mentioned previously in *Methods*, well Cu-11708Z was not included in the max-min analysis.

Summary

The "200-foot," "500-foot," and "700-foot" sands of the Chicot aquifer system underlying southwestern Louisiana are an important source of freshwater in the Lake Charles metropolitan area and the surrounding communities in Calcasieu and Cameron Parishes in southwestern Louisiana. Potentiometric surfaces, water-level difference maps, and concurrent water-withdrawal data are important to help assess the effects of withdrawals, determine the direction of groundwater flow, and develop sustainable groundwaterresource management strategies. To meet this need, the U.S. Geological Survey, in cooperation with the Louisiana Department of Transportation and Development, began a study in 2011 to measure depth to water in a network of 90 wells in order to determine and document water levels in wells screened in the "200-foot," "500-foot," and "700-foot" sands; prepare potentiometric-surface maps; and evaluate differences in the water levels between 1995 and 2011-12.

The lowest water levels in Calcasieu and Cameron Parishes in wells screened in the "200-foot," "500-foot," and "700-foot" sands were approximately 50, 80, and 70 feet (ft) below the National Geodetic Vertical Datum of 1929 (NGVD 29), respectively, and were located specifically in the southern Lake Charles metropolitan area, to the west of Prien Lake, and between the cities of Lake Charles and Sulphur, respectively. The highest water levels in Calcasieu and Cameron Parishes occurring in wells screened in the "200-foot," "500-foot," and "700-foot" sands were approximately 8 ft above NGVD 29, 2 ft below NGVD 29, and 14 ft below NGVD 29, respectively, and were all located in northwestern Calcasieu Parish.

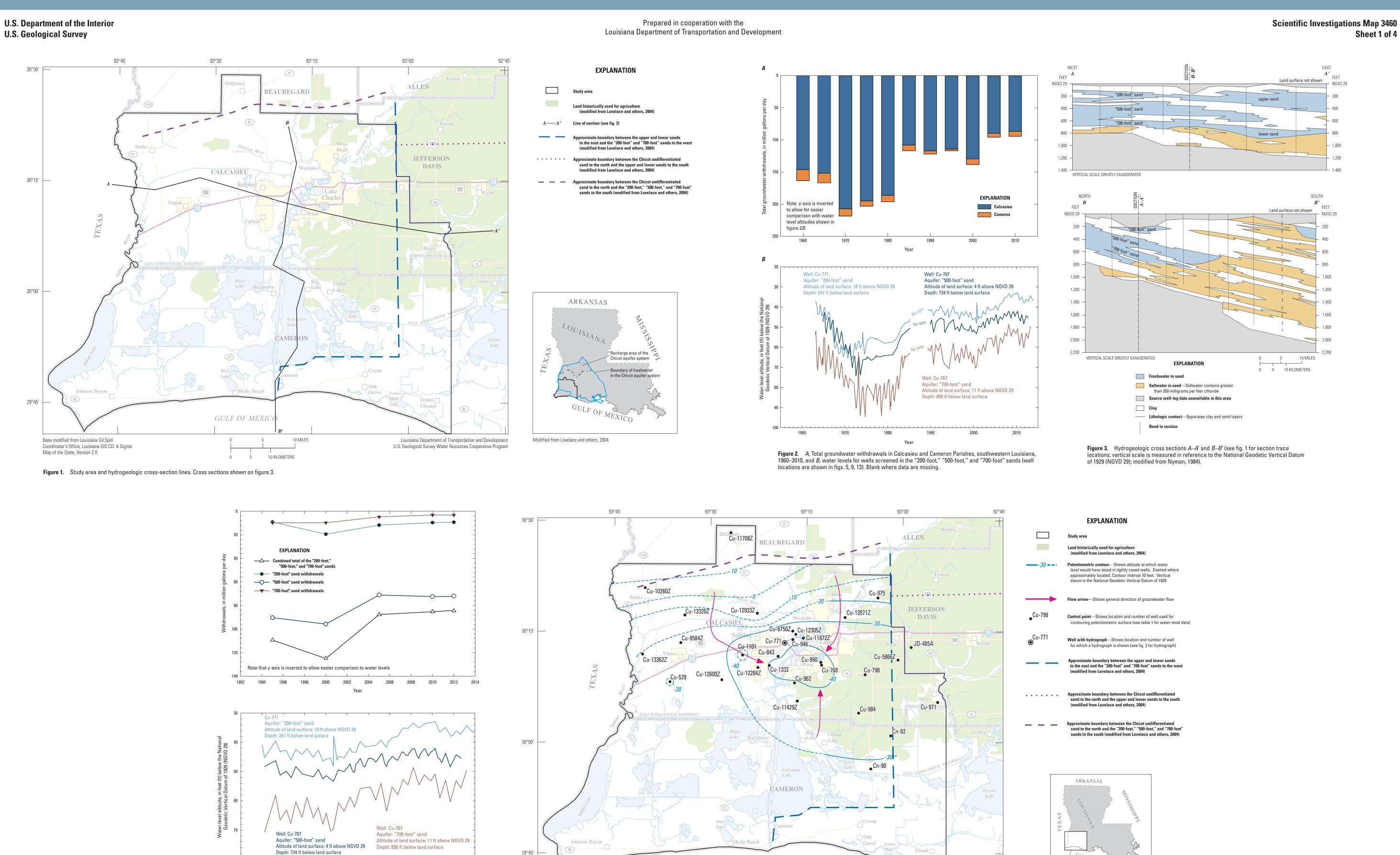
The distribution of water levels in the "200-foot," "500-foot," and "700-foot" sands indicates a primary flow direction towards pumping centers overlying the water-level lows. Between 1995 and 2011–12, maximum water-level increases were approximately 7 ft in the "200-foot" sand, approximately 31 ft in the "500-foot" sand, and approximately 19 ft in the "700-foot" sand. Water-level increases are consistent with a reduction in total withdrawals from these aquifers of about 25 million gallons per day from about 109 million gallons per day in 1995 to about 85 million gallons per day in 2012. Groundwater withdrawals from the "500-foot" sand are the highest by volume and the most influential over water levels in the "200-foot" and "700-foot" sands.

References Cited

Cunningham, W.L., and Schalk, C.W., comps., 2011, Groundwater technical procedures of the U.S. Geological Survey: U.S. Geological Survey Techniques and Methods 1–A1, 151 p. [Also available at http://pubs.usgs.gov/ tm/1a1.]

- Jones, P.H., 1950, Ground-water conditions in the Lake Charles area, Louisiana: U.S. Geological Survey Open-File Report, 16 p.
- Jones, P.H., Turcan, A.N., Jr., and Skibitzke, H.E., 1954,
 Geology and ground-water resources of southwestern
 Louisiana: Louisiana Department of Conservation
 Geological Bulletin no. 30, 285 p.
- Lovelace, J.K., 1998, Distribution of saltwater in the Chicot aquifer system in the Calcasieu Parish area, Louisiana, 1995–96: Louisiana Department of Transportation and Development Water Resources Technical Report no. 62, 59 p.
- Lovelace, J.K., 1999, Distribution of saltwater in the Chicot aquifer system of southwestern Louisiana, 1995–96:
 Louisiana Department of Transportation and Development Water Resources Technical Report no. 66, 61 p.
- Lovelace, J.K., Fontenot, J.W., and Frederick, C.P., 2004, Withdrawals, water levels, and specific conductance in the Chicot aquifer system in southwestern Louisiana, 2000–03: U.S. Geological Survey Scientific Investigations Report 2004–5212, 56 p.
- Lovelace, J.K., Frederick, C.P., Fontenot, J.W., and Naanes,
 M.S., 2001, Louisiana ground-water map no. 12—
 Potentiometric surface of the Chicot aquifer system in southwestern Louisiana, June 2000: U.S. Geological Survey Water-Resources Investigations Report 01–4128, 1 sheet.
- Louisiana Department of Transportation and Development, 2018 Water Resource Studies and Data Dissemination Programs: Water Supply Availability and Use Program, accessed October 1, 2018, at http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Public_Works/Water_Resources/Pages/DataDissem.aspx.
- Louisiana State University AgCenter, 2015, Louisiana rice acreage by variety: Louisiana State University Rice Acreage Reports, accessed September 24, 2015, at http://www.lsuagcenter.com/en/crops_livestock/crops/rice/Statistics/Rice-Varieties.htm.
- National Oceanic and Atmospheric Administration, 2011, Local climatological data annual summary with comparative data—Lake Charles, Louisiana (KLCH): Asheville, N.C., Environmental Data Service, 8 p., accessed January 10, 2013, at http://cdo.ncdc.noaa.gov/annual/2011/2011LCH.pdf.
- Nyman, D.J., 1984, The occurrence of high concentrations of chlorides in the Chicot aquifer system of southwestern Louisiana: Louisiana Department of Transportation and Development Water Resources Technical Report no. 33, 75 p.





Potentiometric Surfaces, 2011–12, and Water-Level Differences Between 1995 and 2011–12, in Wells of the "200-Foot," "500-Foot," and "700-Foot" Sands of the Lake Charles Area, Southwestern Louisiana

GULF OF MEXICO

10 MILES

Figure 5. Potentiometric surface of wells screened in the "200-foot" sand of the Lake Charles area and upper and undifferentiated sands of the Chicot aquifer system, southwestern Louisiana, December 2011–March 2012.

Chenier

Louisiana Department of Transportation and Development U.S. Geological Survey Water Resources Cooperative Program

1998 2000 2002

Figure 4. A, Groundwater withdrawals and B, water levels from wells screened in the "200-

foot," "500-foot," and "700-foot" sands of the Lake Charles area in Calcasieu and Cameron

Vertical Datum of 1929 (NGVD 29); well locations are shown on figs. 5, 9, and 13).

Parishes, southwestern Louisiana (water levels are presented in feet below the National Geodetic

2006

2008 2010 2012 2014

Base modified from Louisiana Oil Spill

Map of the State, Version 2.0

Coordinator's Office, Louisiana GIS CD: A Digital

and does not imply endorsement by the U.S. Government

Digital files available at https://doi.org/10.3133/sim3460

Any use of trade, product, or firm names in this publication is for descriptive purposes only

For sale by U.S. Geological Survey, Information Services, Box 25286, Federal Center,

- Nyman, D.J., Halford, K.J., and Martin, A., Jr., 1990, Geohydrology and simulation of flow in the Chicot aquifer system of southwestern Louisiana: Louisiana Department of Transportation and Development Water Resources Technical Report no. 50, 58 p.
- U.S. Census Bureau, 2019, Quickfacts, accessed September 16, 2019, at https://www.census.gov/quickfacts/fact/table/lakecharlescitylouisiana,US/PST045218.
- U.S. Environmental Protection Agency, 2016, Secondary Drinking Water Standards—Guidance for nuisance chemicals, accessed April 13, 2016, at https://www.epa.gov/ dwstandardsregulations/secondary-drinking-water-standardsguidance-nuisance-chemicals.
- U.S. Geological Survey, 2015, National Water Information System—Mapper, accessed September 15, 2015, at http://maps.waterdata.usgs.gov/mapper/index.html?state=la\.
- U.S. Geological Survey, 2017a, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed February 1, 2017, at https://doi. org/10.5066/F7P55KJN.
- U.S. Geological Survey, 2017b, U.S. Geological Survey Water Resources Cooperative Program—Louisiana Water Use Program, accessed April 3, 2017, at https://la.water.usgs.gov/WaterUse/default.asp.

For more information about this publication, contact
Director, Lower Mississippi-Gulf Water Science Center
U.S. Geological Survey
640 Grassmere Park, Suite 100
Nashville, TN 37211

For additional information, visit https://www.usgs.gov/centers/lmg-water/

Publishing support provided by Lafayette Publishing Service Center